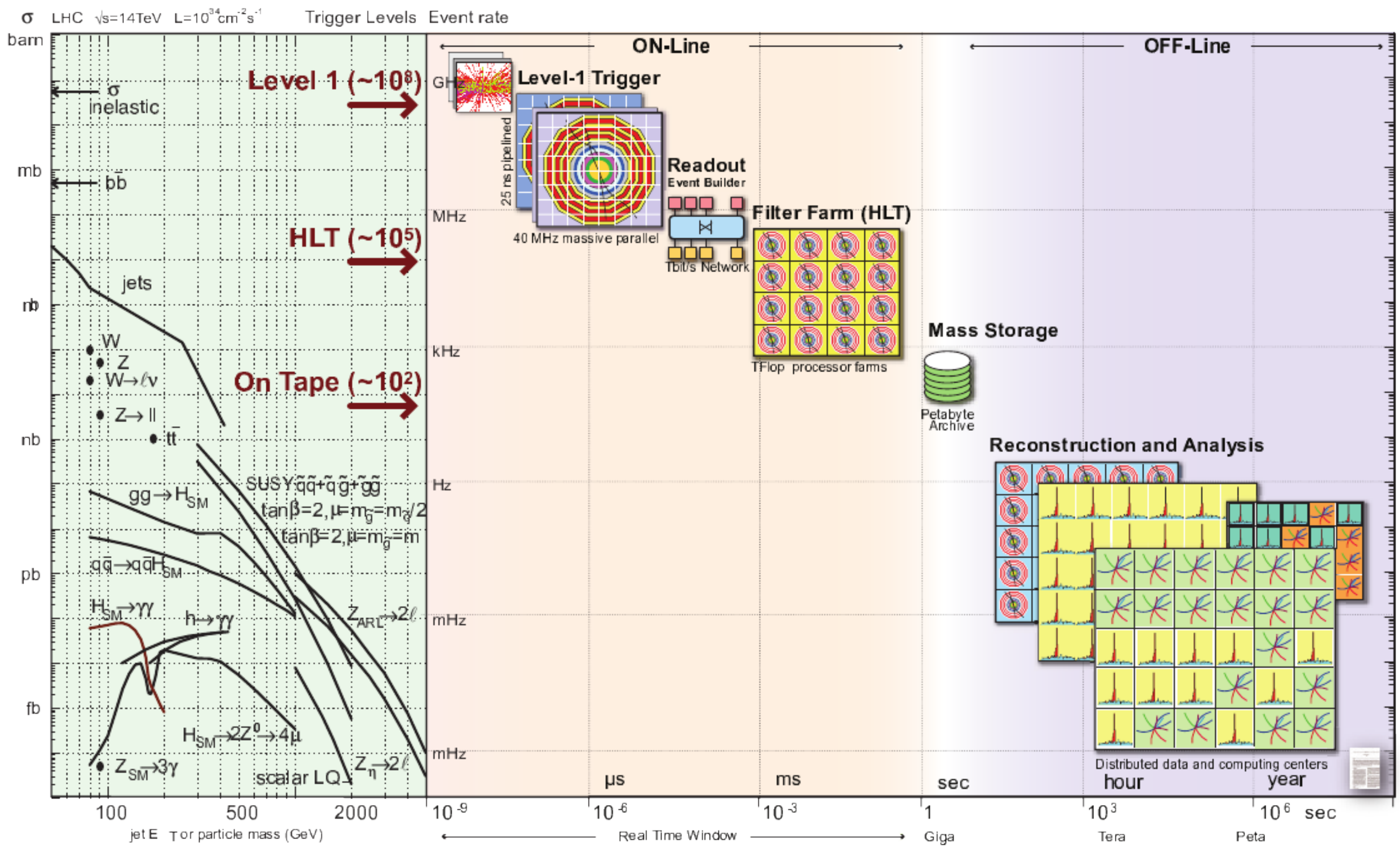
# CMS Trigger performance challenges in Run2

Andrea Bocci

# CMS Trigger System




- CMS has been designed with a two-level trigger system:
    - Level 1 Trigger
    - High Level Trigger

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- fast readout of the detector, with a limited granularity, at the 40 MHz LHC rate

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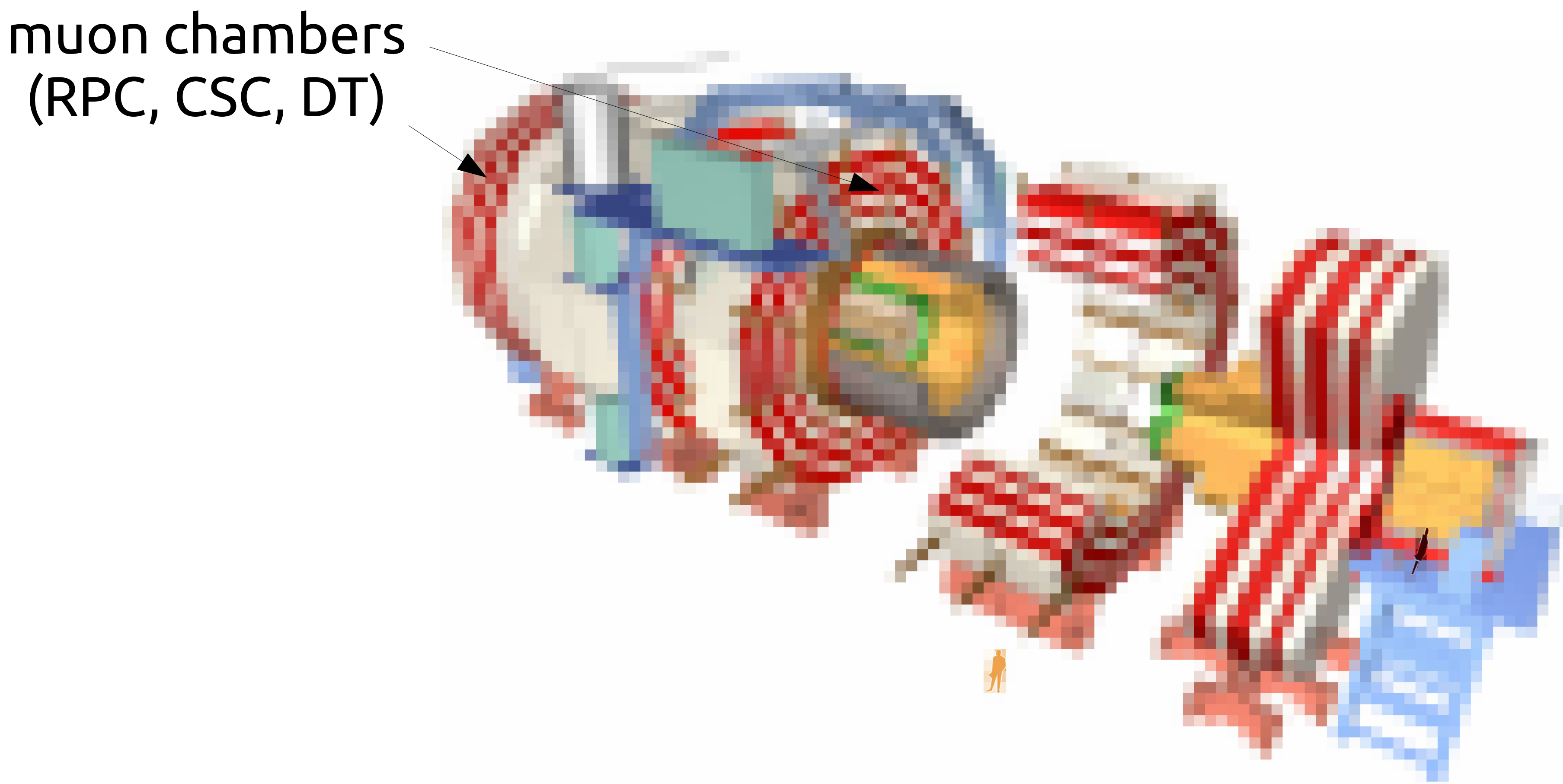

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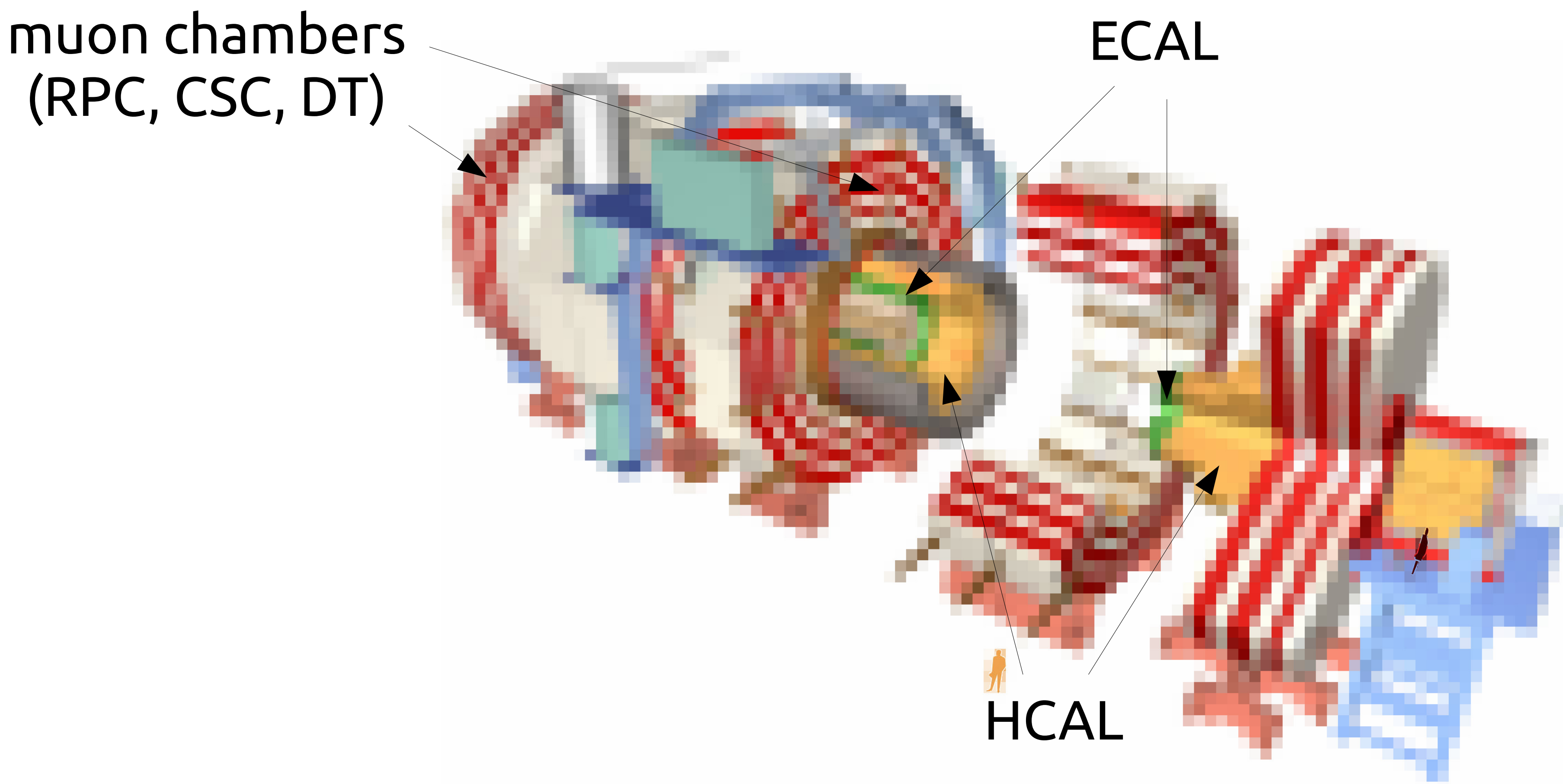

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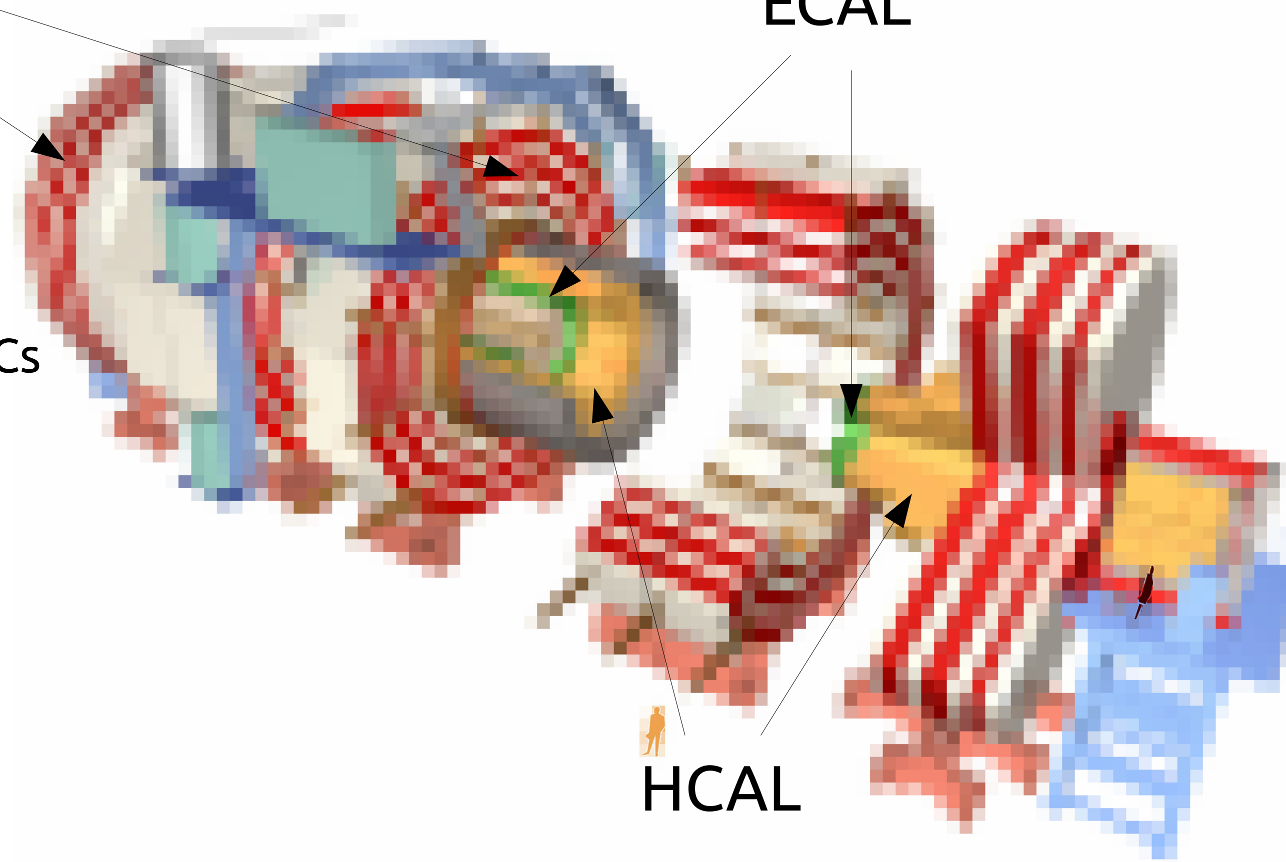


- implementation
  - hardware: FPGAs and ASICs
  - synchronous operation

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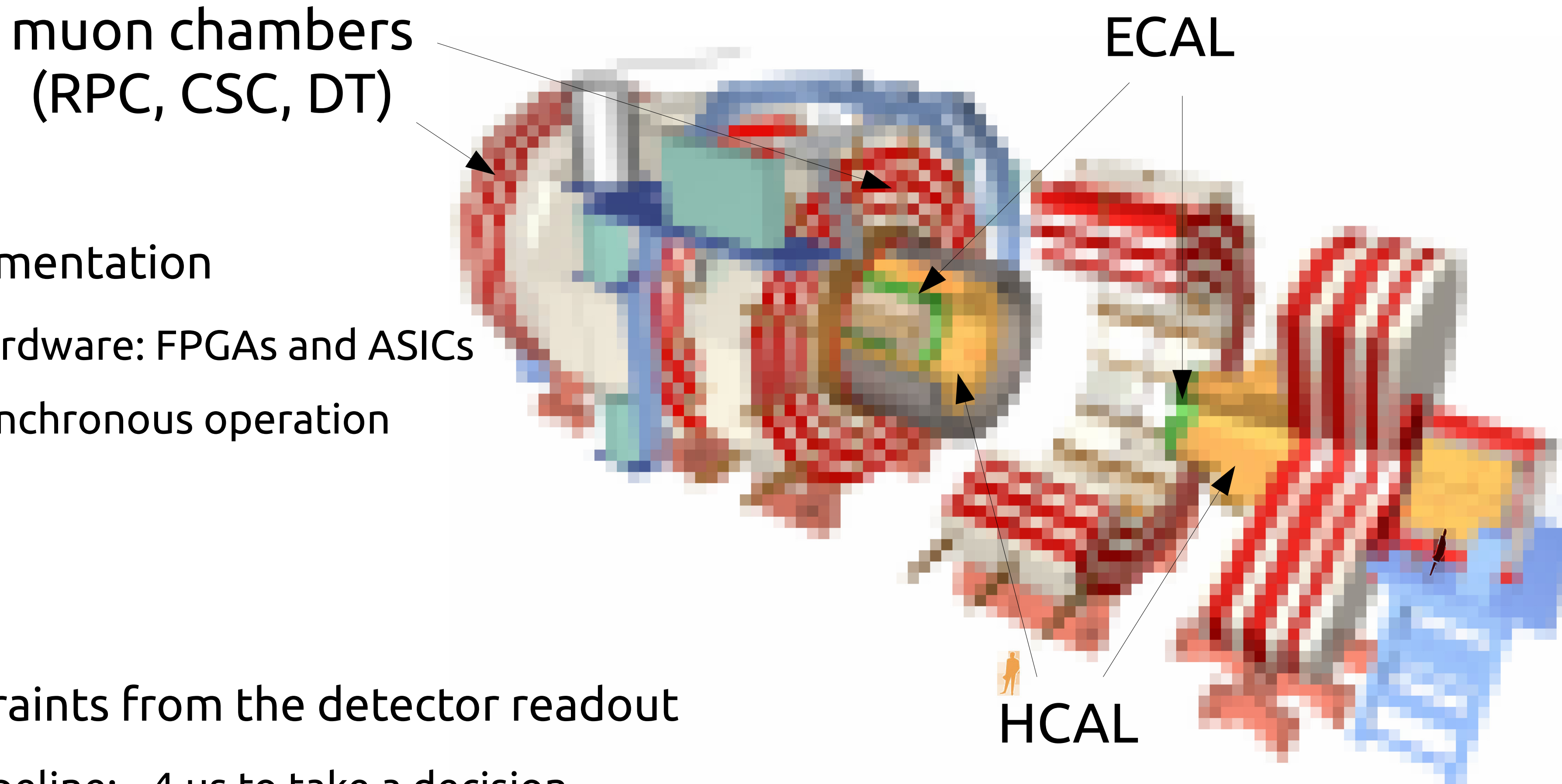
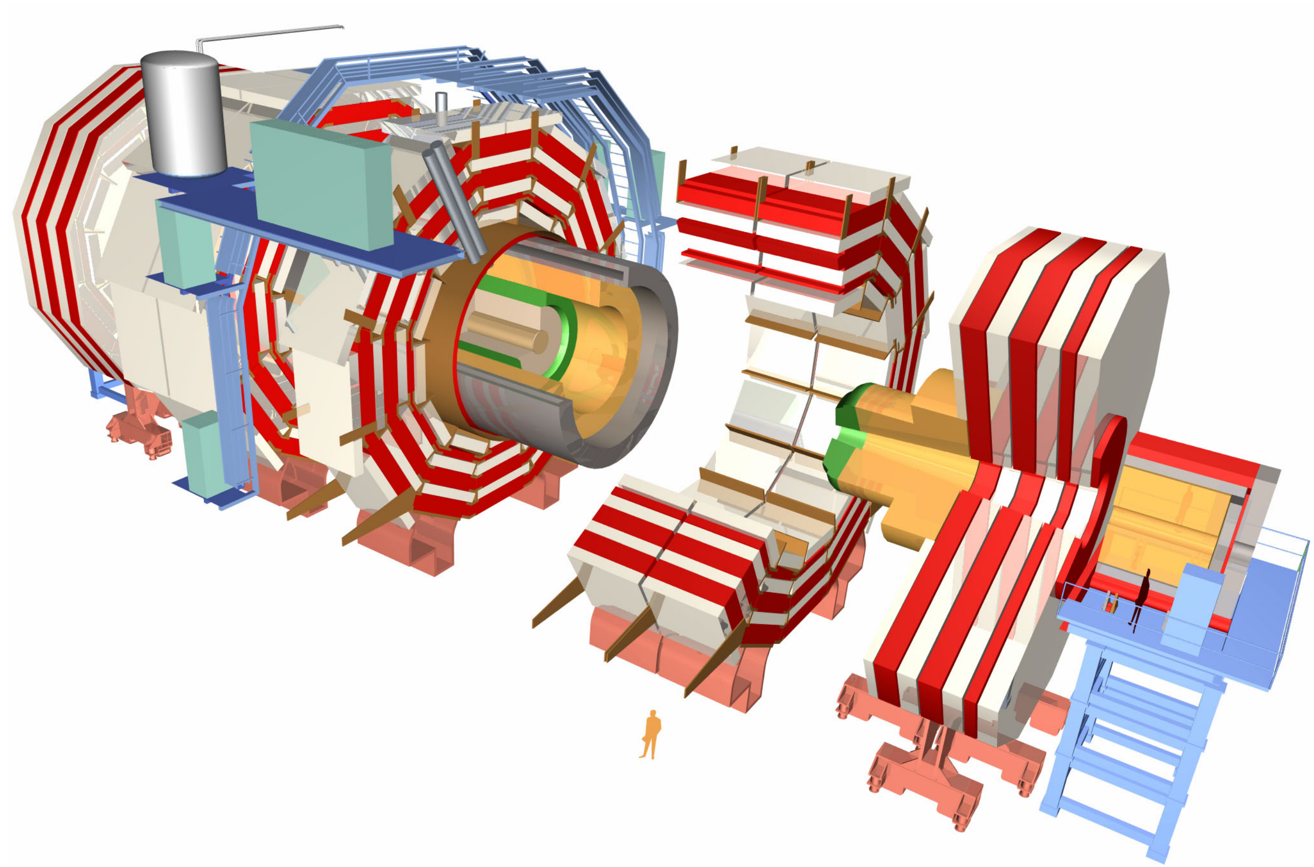



- implementation
  - hardware: FPGAs and ASICs
  - synchronous operation

- constraints from the detector readout
  - pipeline: ~4 μs to take a decision
  - readout: 100 kHz maximum output rate

# High Level Trigger

- full readout of the detector at the L1 accept rate (up to 100 kHz)



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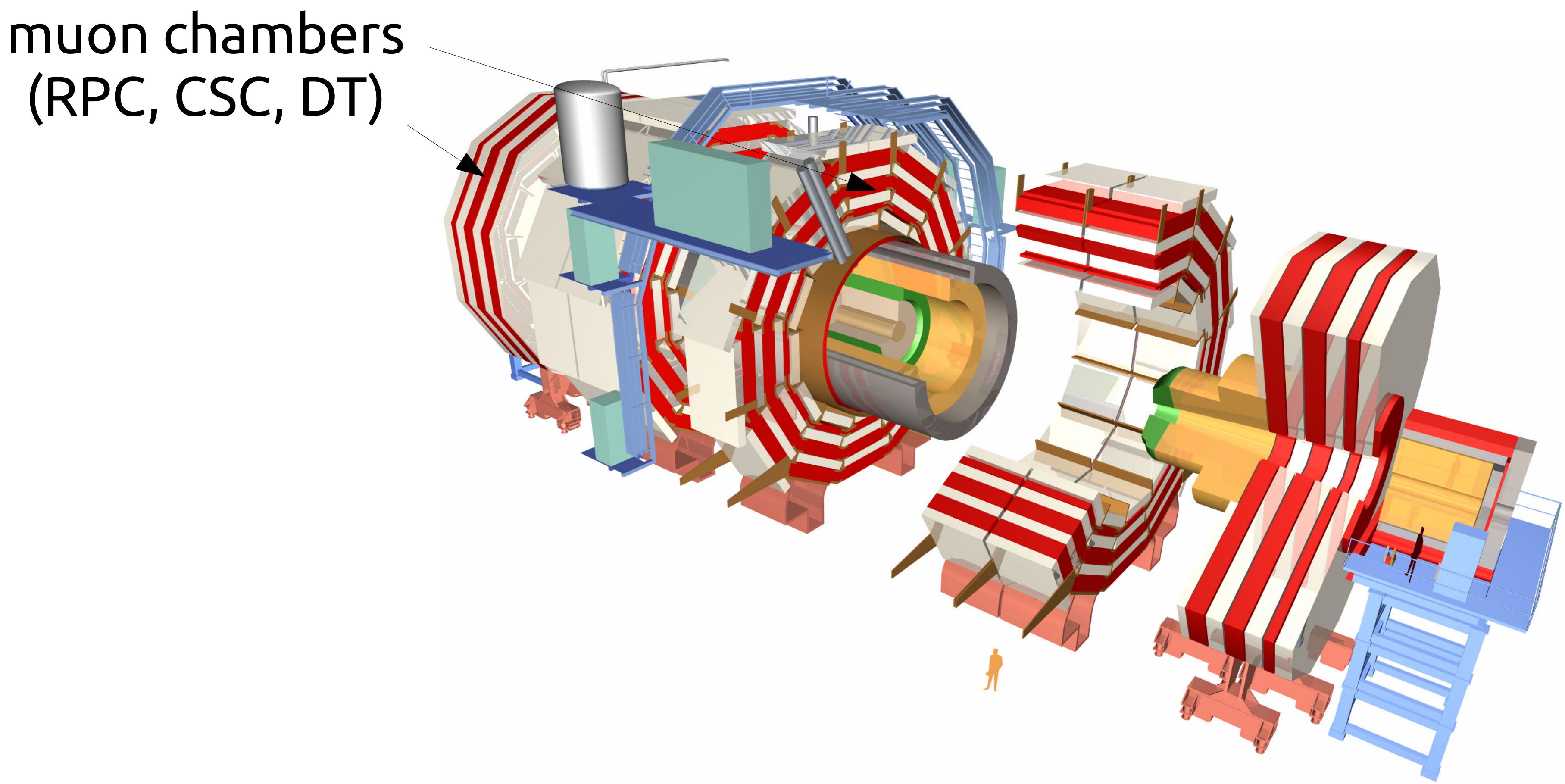

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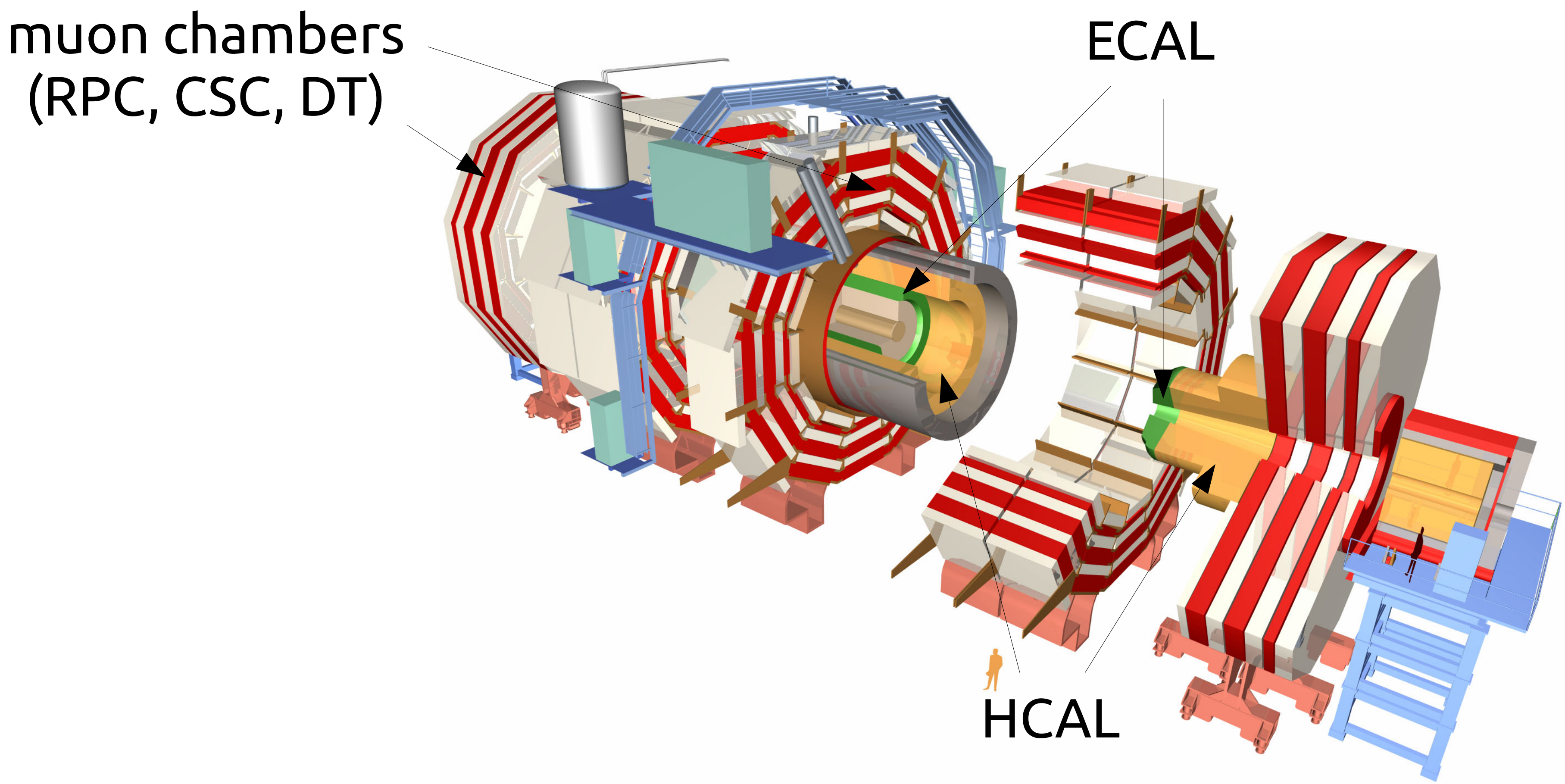

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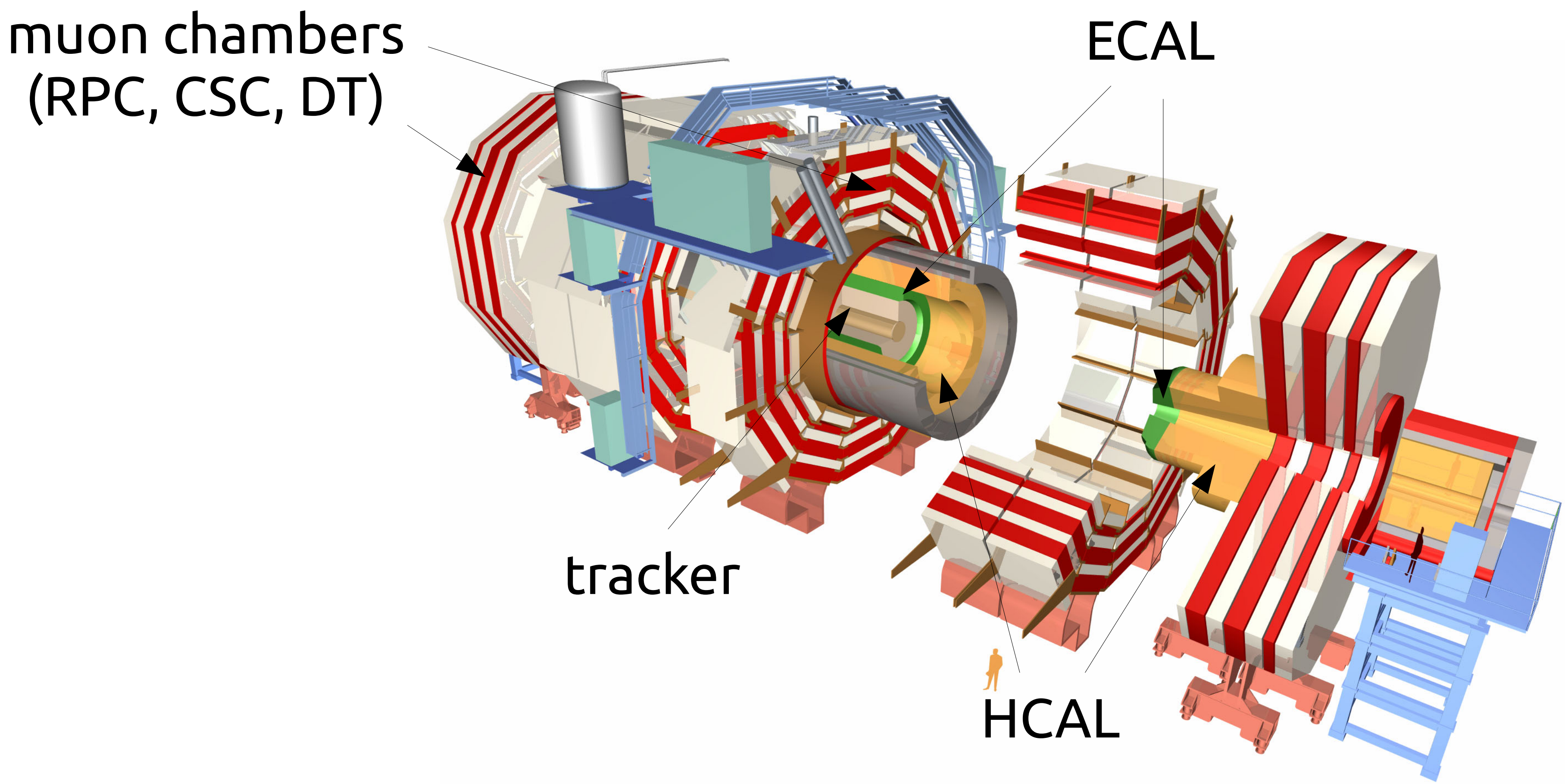

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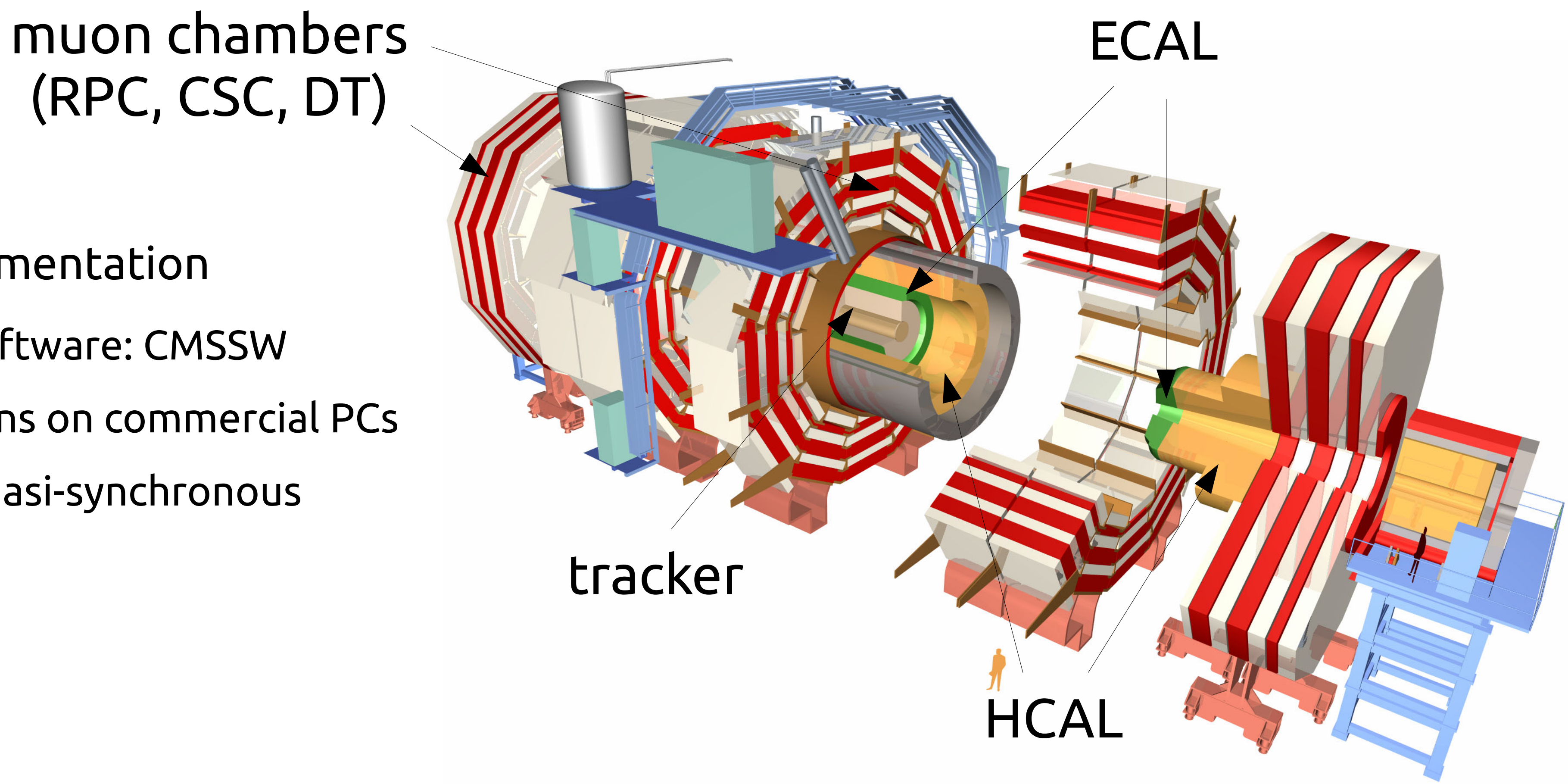


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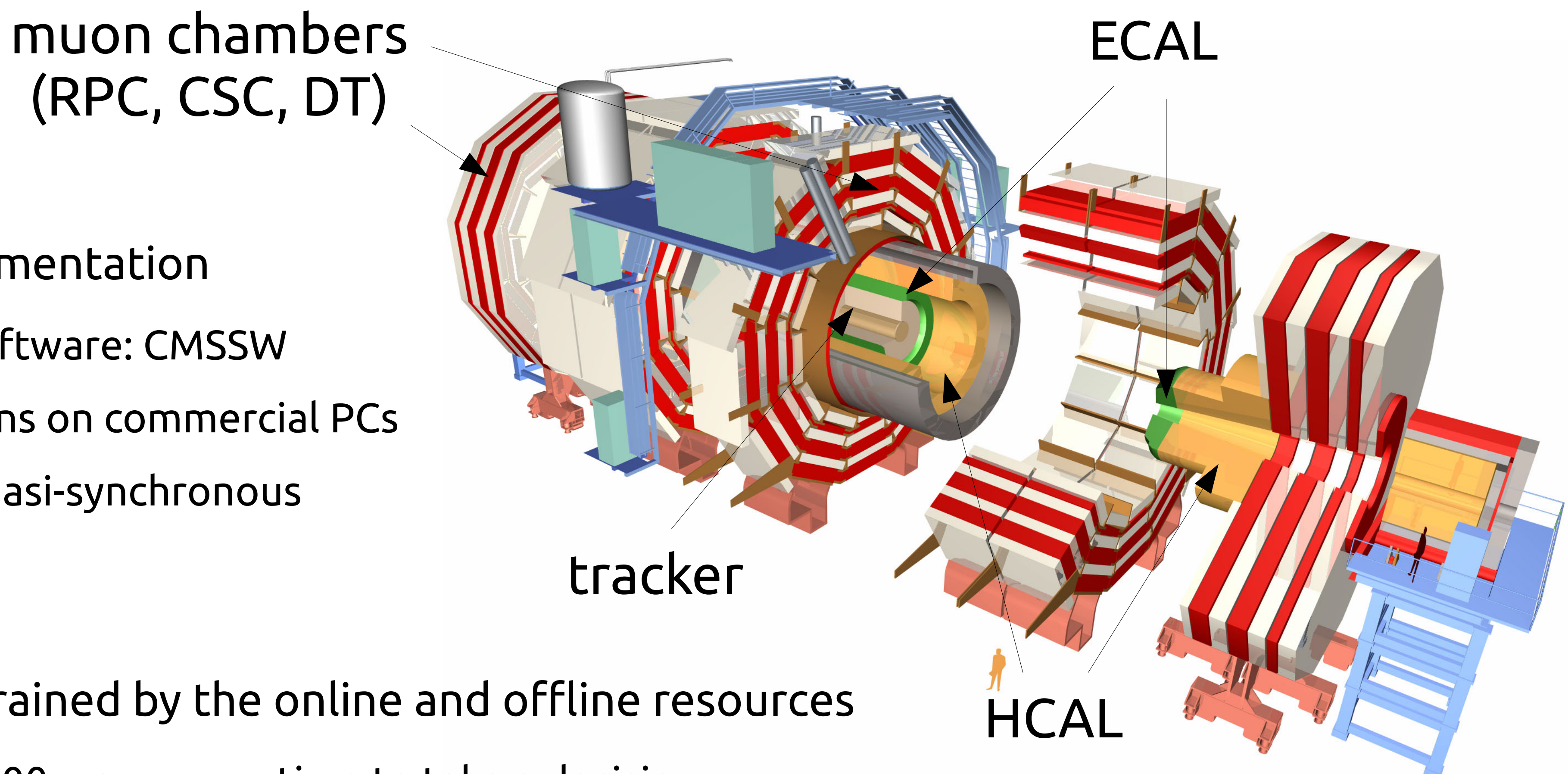


- implementation
  - software: CMSSW
  - runs on commercial PCs
  - quasi-synchronous

- constrained by the online and offline resources
  - ~300 ms *average* time to take a decision
  - ~1 kHz *average* output rate

# Challenges for Run 2

- in 2012, we had:
  - 8 TeV collisions
  - peak luminosity of ~7.5e33 $cm^{-2}s^{-1}$
  - peak in-time pileup of ~35 interactions/bunch crossing
  - 50 ns operations: negligible contribution from out-of-time pileup

- in 2015, we expect:
  - 13 TeV collisions
  - target luminosity of 1.6e34 $cm^{-2}s^{-1}$
  - peak in-time pileup of ~45 interactions/bunch crossing
  - 25 ns operations: possibly large impact from out-of-time pileup
    - especially on the calorimeters

# Challenges for Run 2

- in 2012, we had:
  - **8 TeV** collisions
  - peak luminosity of ~7.5e3
  - peak in-time pileup of ~3
  - 50 ns operations: negligi

- in 2015, we expect:
  - **13 TeV** collisions
  - target luminosity of 1
  - peak in-time pileup of ~4
  - 25 ns operations: possibly
    - especially on the calorimeters

- higher cross-sections due to the higher parton energy
- from MC simulations we expect higher trigger rates by varying factors:
  - a factor **x1.5** ~ **x2** for leptons
  - a factor **x2** ~ **x3** for photons
  - a factor **x4** and **higher** for jets, HT and MET

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- factor **x2** higher rates

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- **similar in-time pileup** conditions
- build on top of the **pileup rejection** techniques used in 2012

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- new mode of operation for the detectors
  - **new calibrations**
  - **dedicated reconstruction** for the rejection of out-of-time pileup

- in
  - peak in-time pileup of ~45 interactions/bunch
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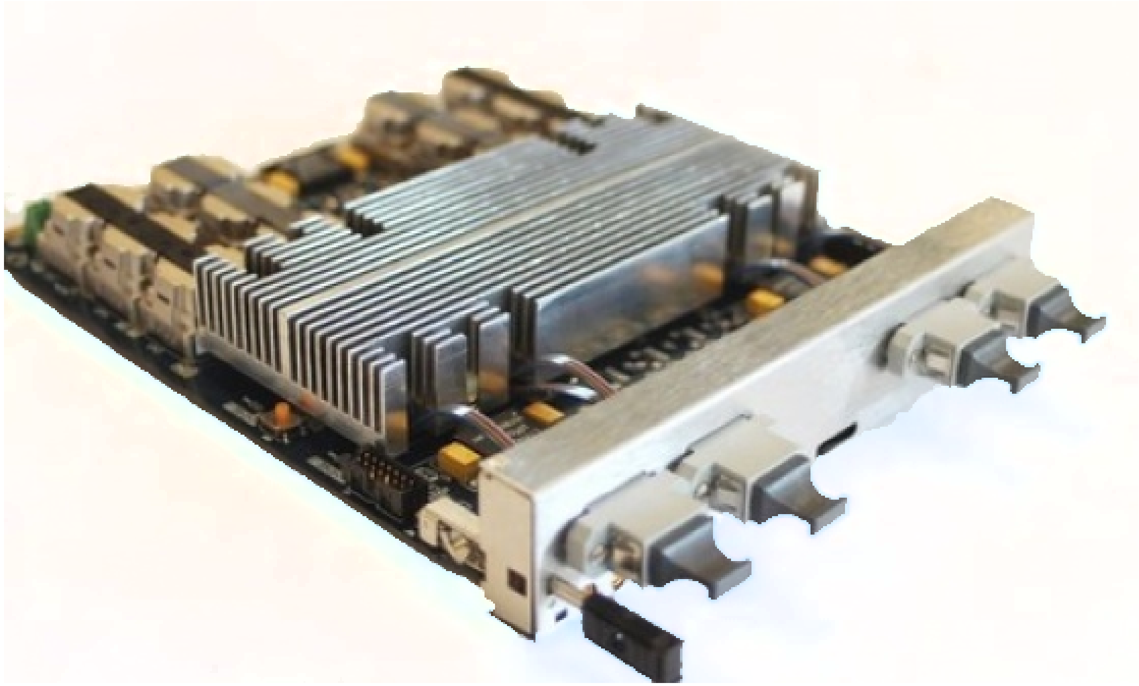
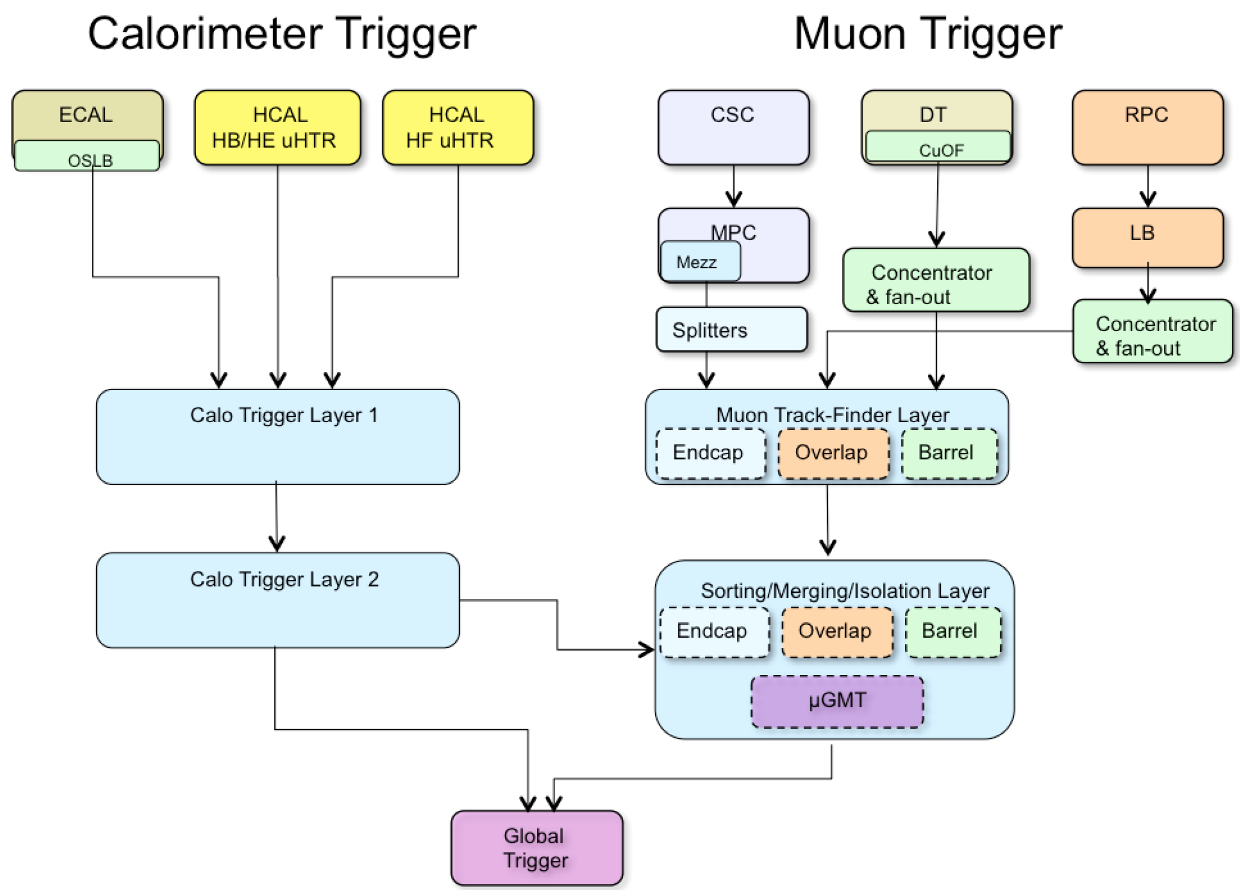
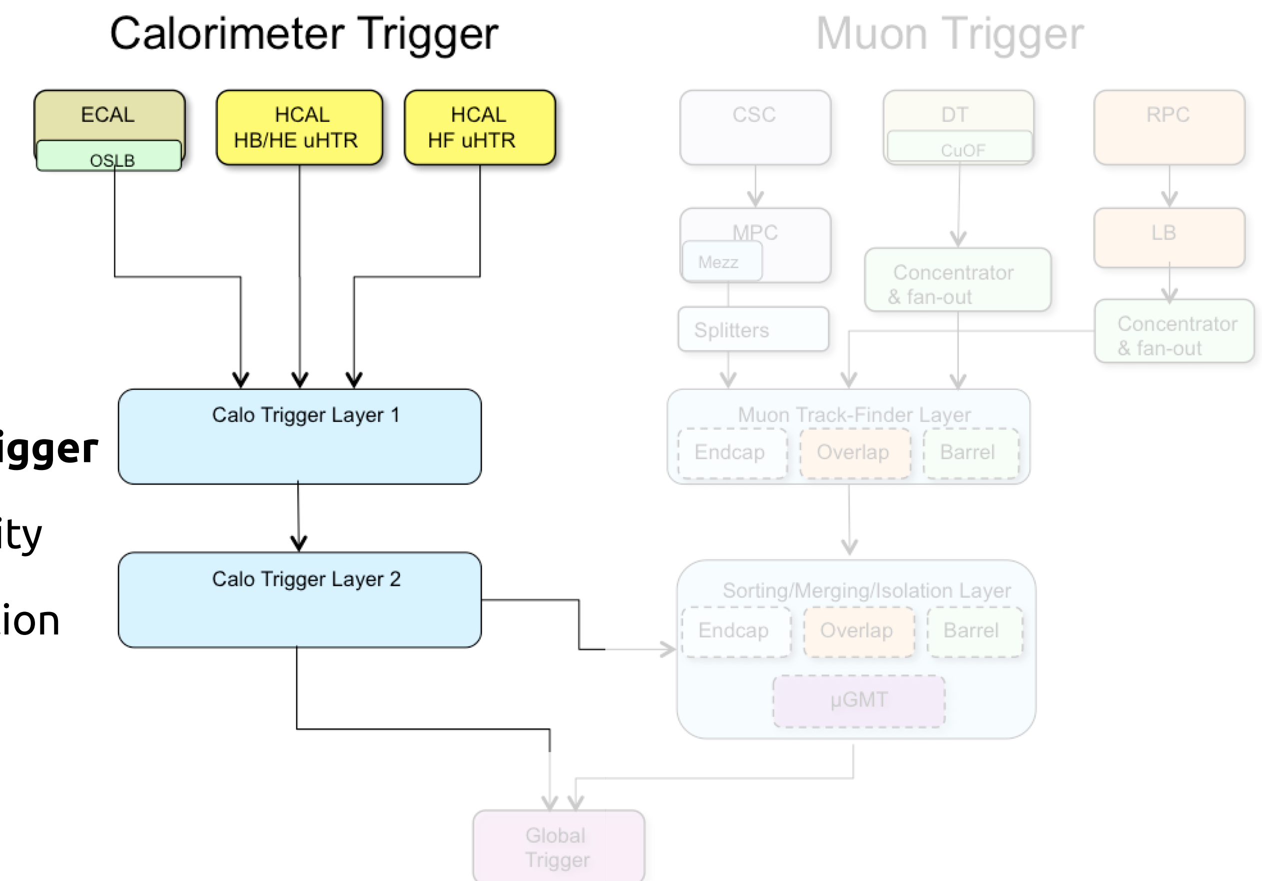


# Level 1 Trigger in 2016



# Level 1 Trigger in 2016

- two-layer **Calorimeter Trigger**
- higher granularity
- pile-up subtraction



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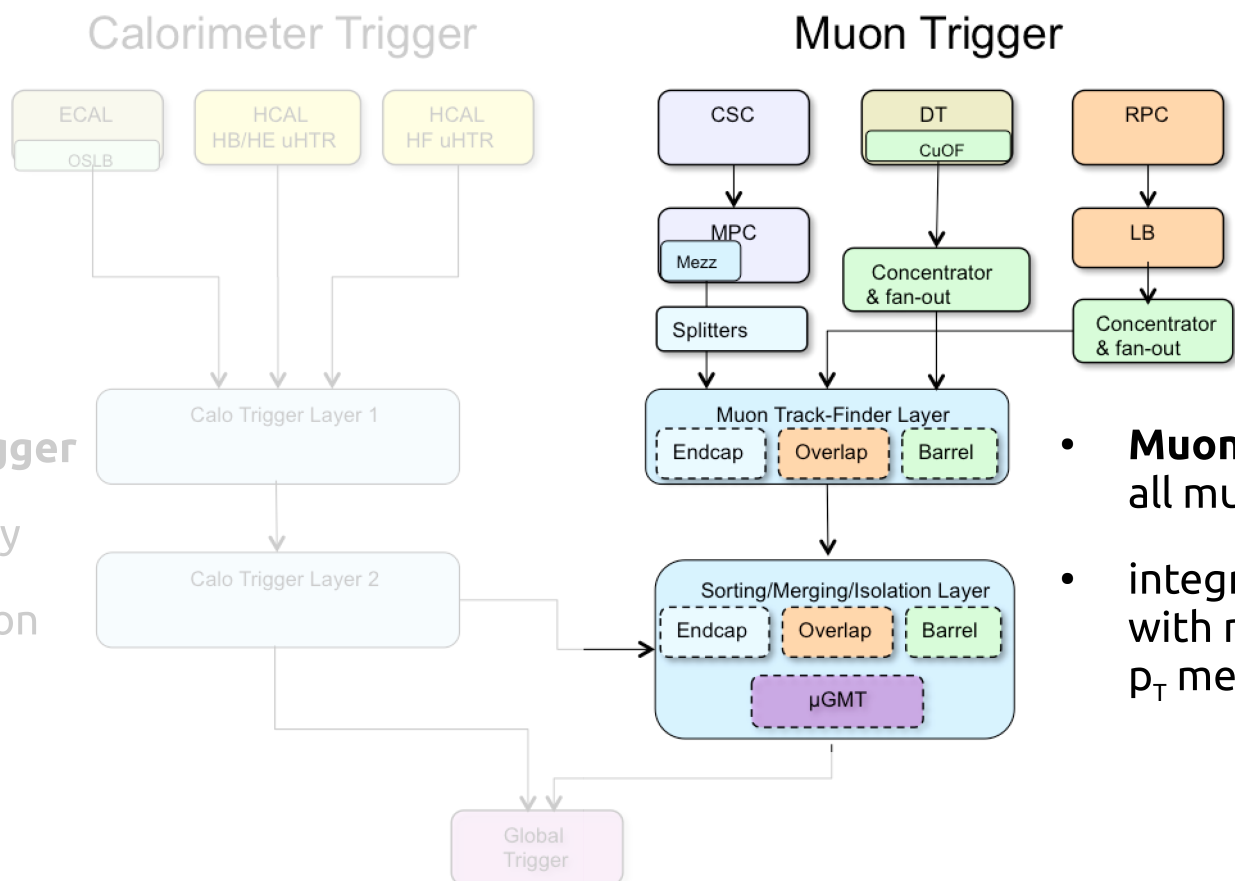


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- integrated track-finding with more sophisticated $p_T$ measurement

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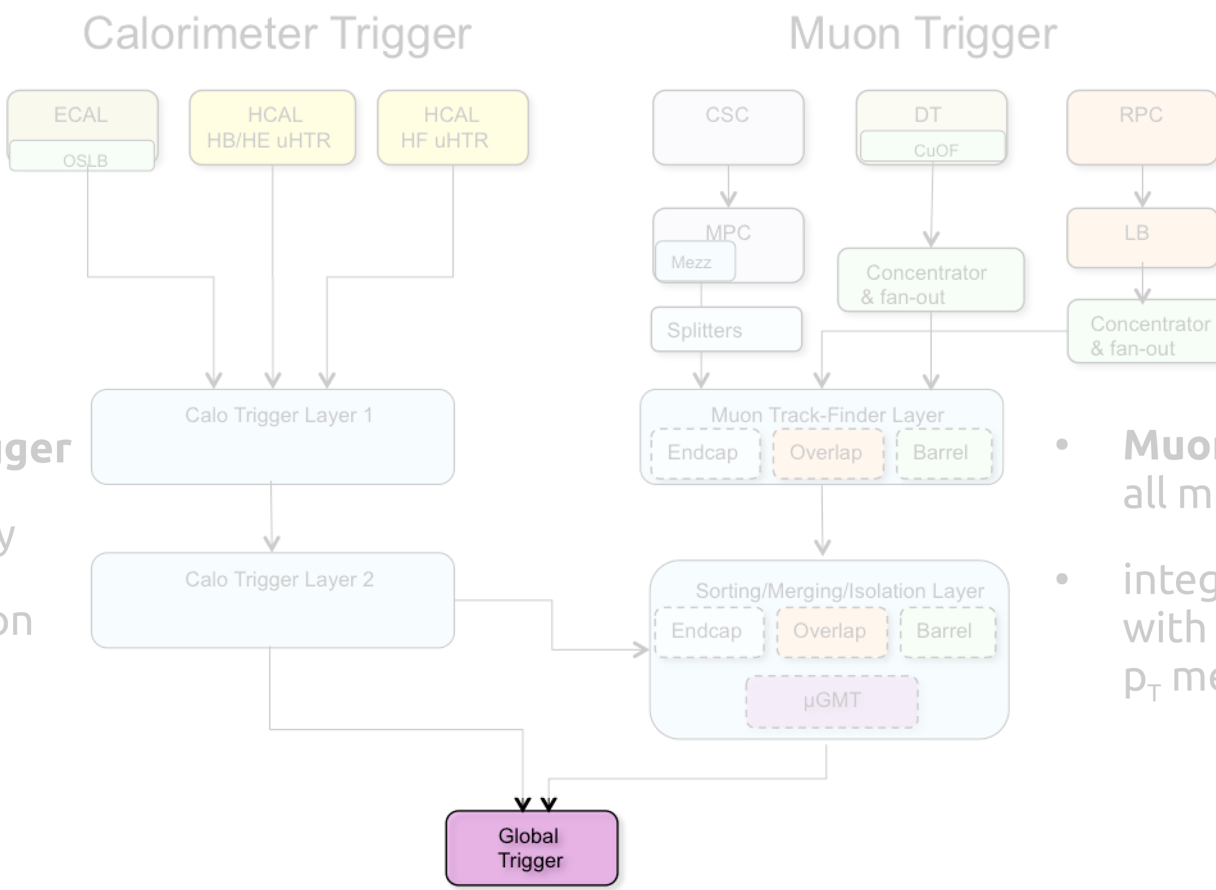


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- integrated track-finding with more sophisticated $p_T$ measurement

- more powerful Global Trigger
  - topology cuts, invariant mass cuts, …
  - larger number of triggers

# Stage 1: Level 1 Trigger in 2015

- replace the Global Calorimetric Trigger with a a prototype of the "Layer 2"
  - improved calorimetric trigger
    - pile-up subtraction for jets and energy sums
    - dedicated tau trigger candidates
- improvements to the Muon Trigger
  - make use of new muon chambers
  - increased granularity of the CSC readout
  - improve the LUTs used for track building and matching
- status: software emulation of the new system is ready
  - being integrated in the CMS software
    - Monte Carlo simulation
    - commissioning of the new hardware
  - algorithms still being tuned

# Pileup subtraction in the L1 Trigger

- different algorithms are being considered
- best performance estimating the pileup from the occupancy of the calorimeter
  - number of trigger towers above a certain threshold

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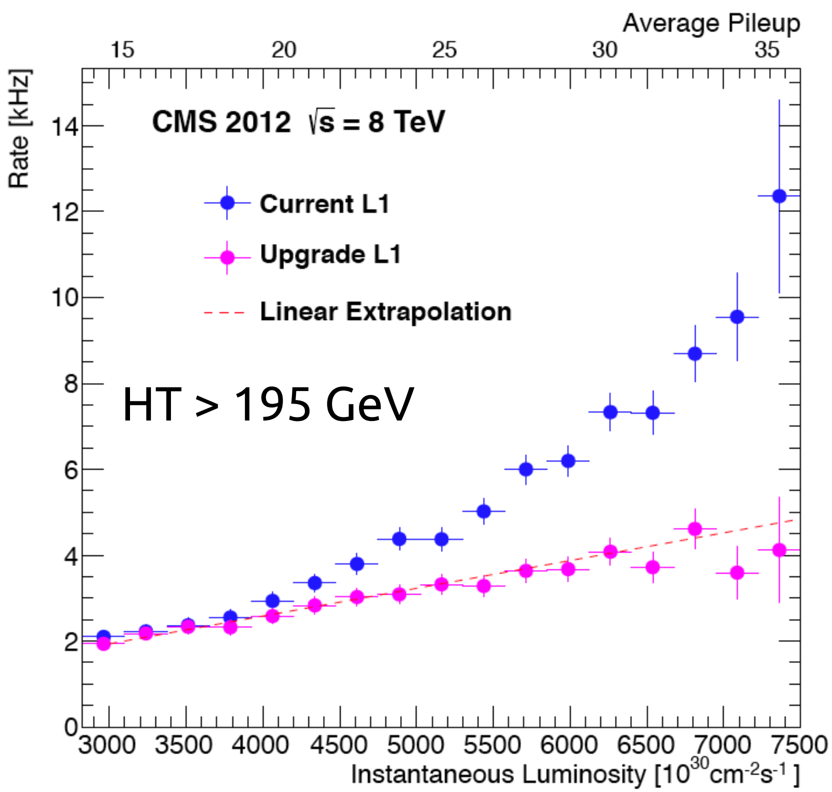
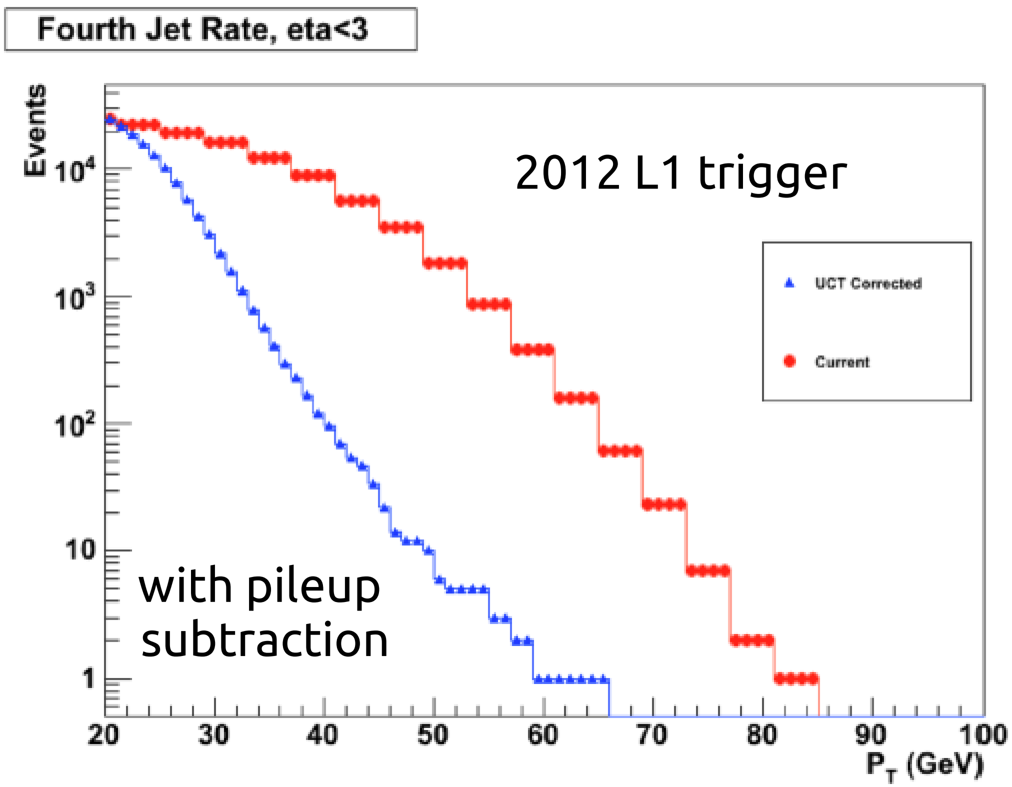
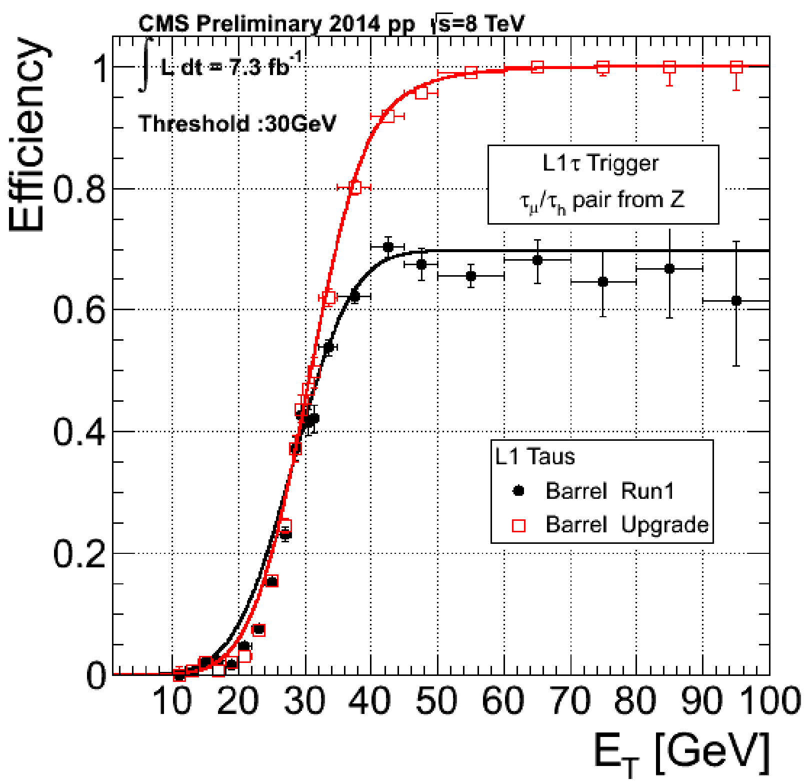


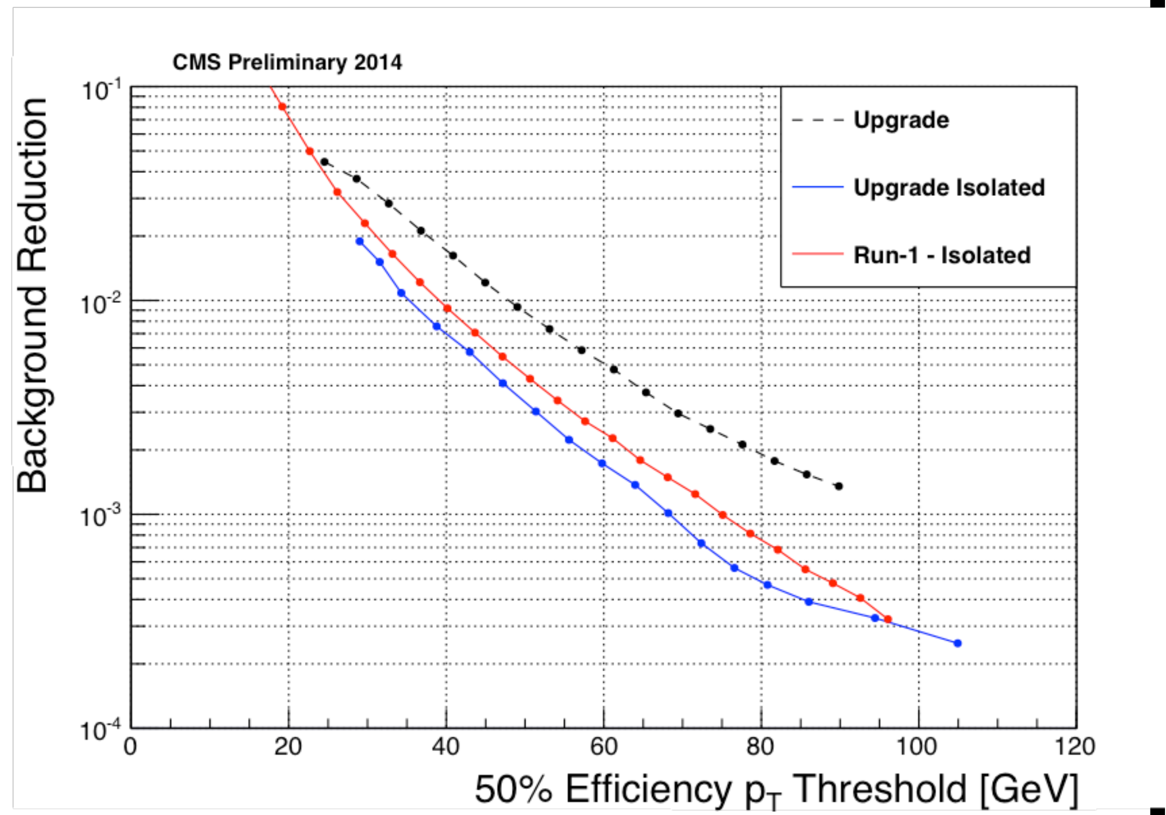




- effect of pile-up subtraction on energy sums and multi-jet trigger

# Tau L1 Trigger improvements

- tau trigger with improved granularity
  - efficiency significantly improved over Run 1
- μ + τ trigger
  - 30% rate reduction and higher efficiency

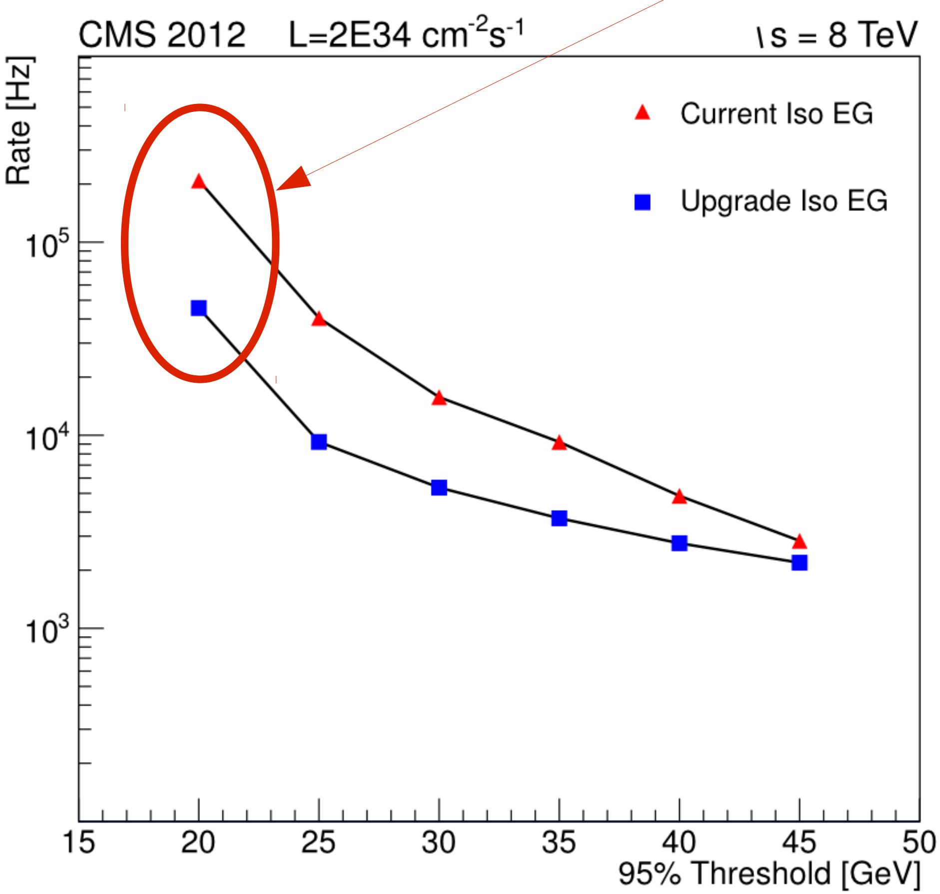


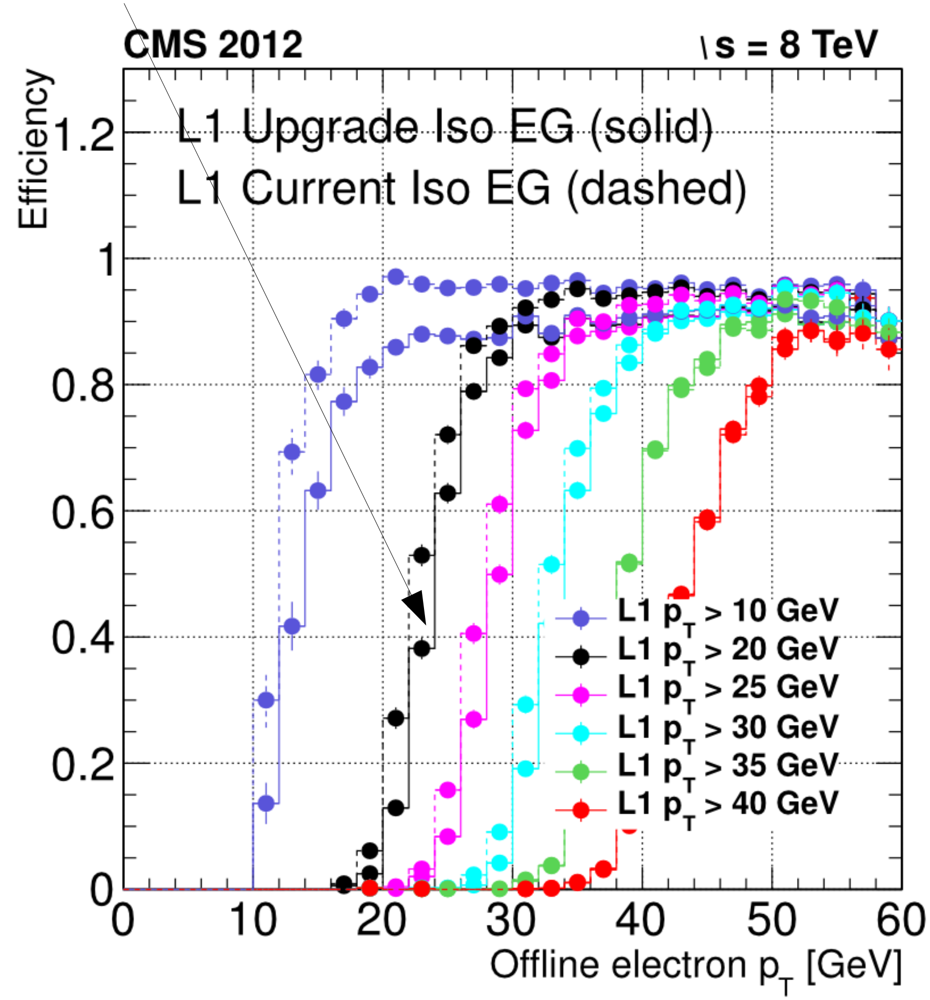




- L1 tau candidates being further improved:
  - different region sizes under study
  - different isolation thresholds

# E/Gamma L1 Trigger improvements

rate reduction by a **factor 5**, with a **similar** efficiency



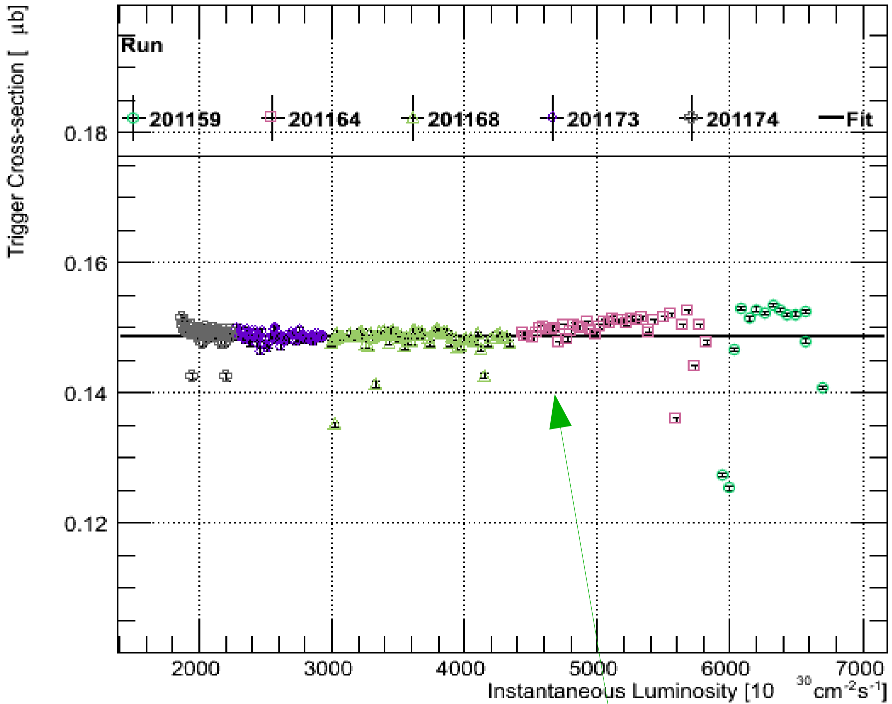



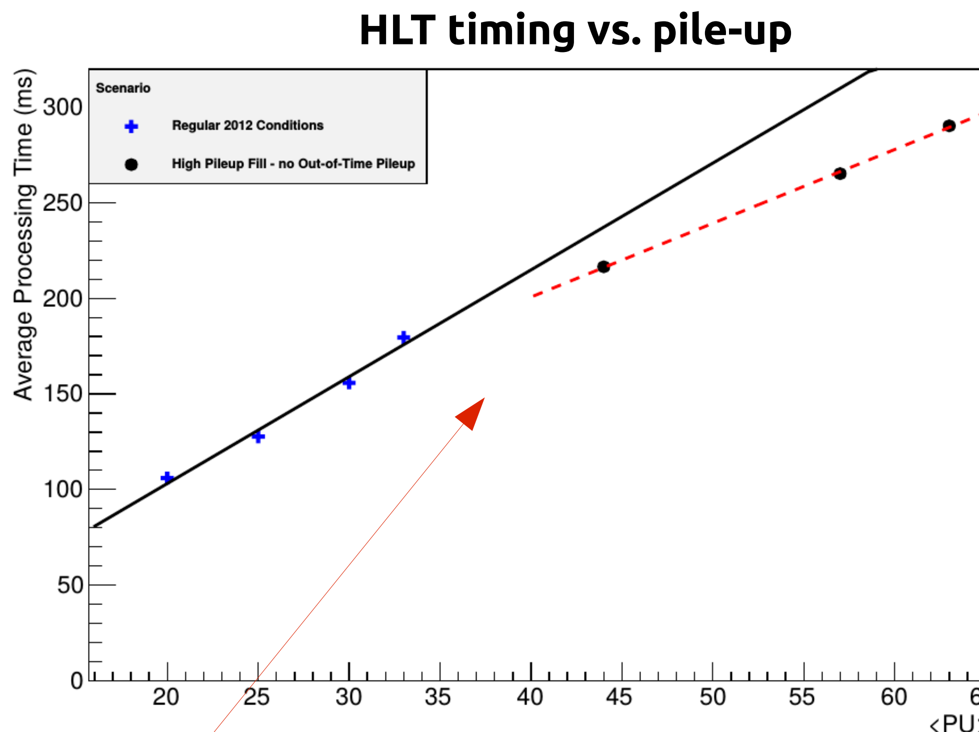

- improved e/gamma isolation at L1

# High Level Trigger for 2015

- more than **double** the HLT rate
  - **400 kHz → 1 kHz**
  - increase in offline storage and processing power
  - still need an effective **reduction by a factor ~2**
- reduce effective rate by a factor 2, keeping the **same physics acceptance**
  - improve **online reconstruction and calibrations** to better match the offline and analysis objects
    - wider use of tracking and particle-flow based techniques
    - reduce the difference between online and analysis selection cuts
- increase the available computing power of the HLT farm
  - by roughly **50%**
  - to cope with **higher pileup** and **more complex reconstruction** code

# High Level Trigger for 2015




higher pileup

- maximum average pileup ~ 45, close to the 2012 value (~35)
- overall HLT rate is **robust** against pile-up
- the HLT cpu usage increases **linearly** with pile-up

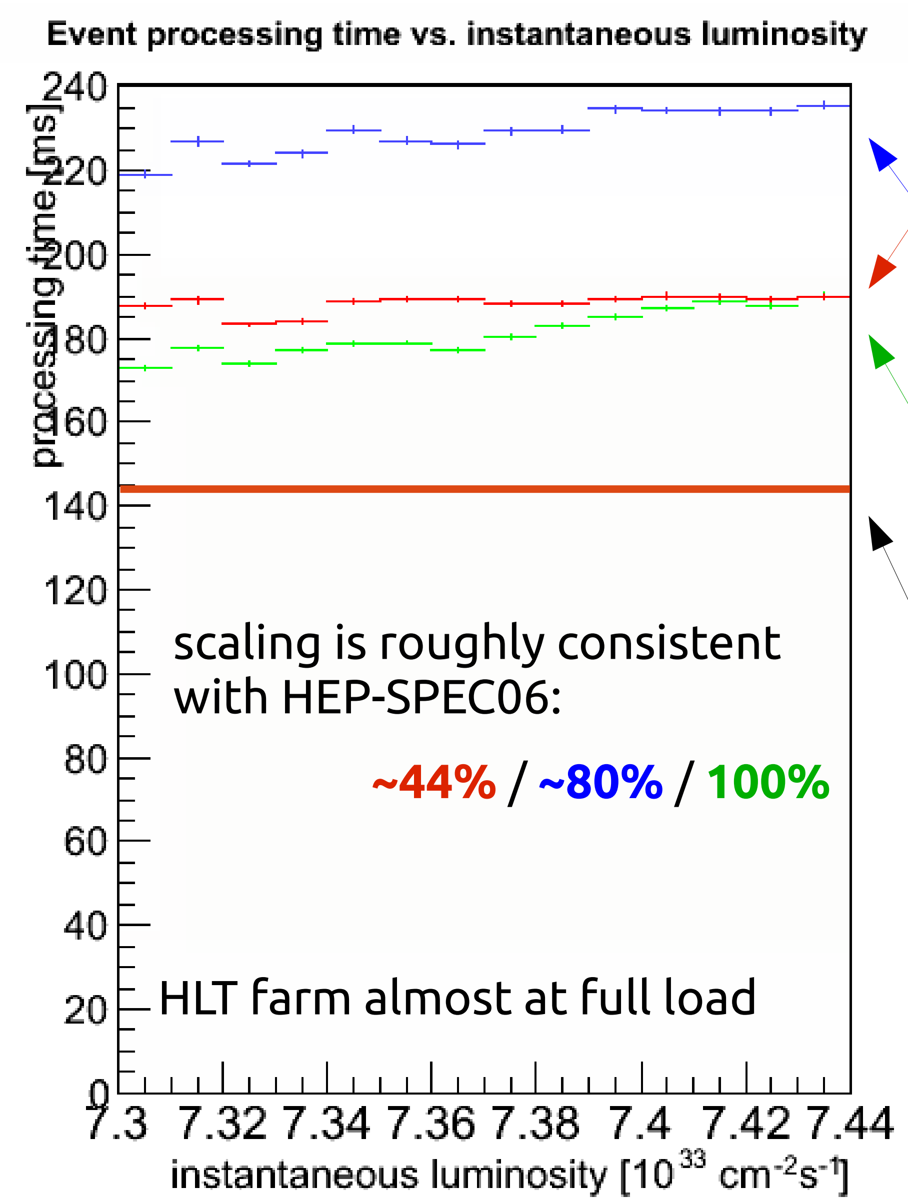
# HLT farm



| | *May 2011* | *May 2012* | *Early 2015* |
|---|---|---|---|
| DAQ Version | DAQ-1 | DAQ-1 | DAQ-2 |
| Model | Dell Power Edge c6100 | Dell Power Edge c6220 | To be decided |
| Form factor | 4 motherboards in 2U box | 4 motherboards in 2U box | |
| **CPUs** per mother-board | 2 x **6-core** Intel Xeon 5650 **Westmere**, 2.66 GHz, hyper-threading, 24 GB RAM | 2 x **8-core** Intel Xeon E5-2670 **Sandy Bridge**, 2.6 GHz, hyper-threading, 32 GB RAM | 2 x **14-core** Intel **Haswell** |
| # Motherboards | 288 | 256 | 256 |
| **# Cores** | **3456** | **4096** | **7168** |
| Data link | 2 x 1Gb/s | 2 x 1Gb/s | 1 x 10 Gb/s |

~15k cores (**~30k processes** or threads) ← **50% more processing power** than in 2012

# performance comparison




scaling is roughly consistent with HEP-SPEC06:

**~44%** / **~80%** / **100%**

HLT farm almost at full load

***Harpertown*** cores: ~ 50% of **SB**

- retired HLT nodes (from 2008)

***Westmere-EP*** cores: ~ 80% of **SB**

- 2011 HLT nodes

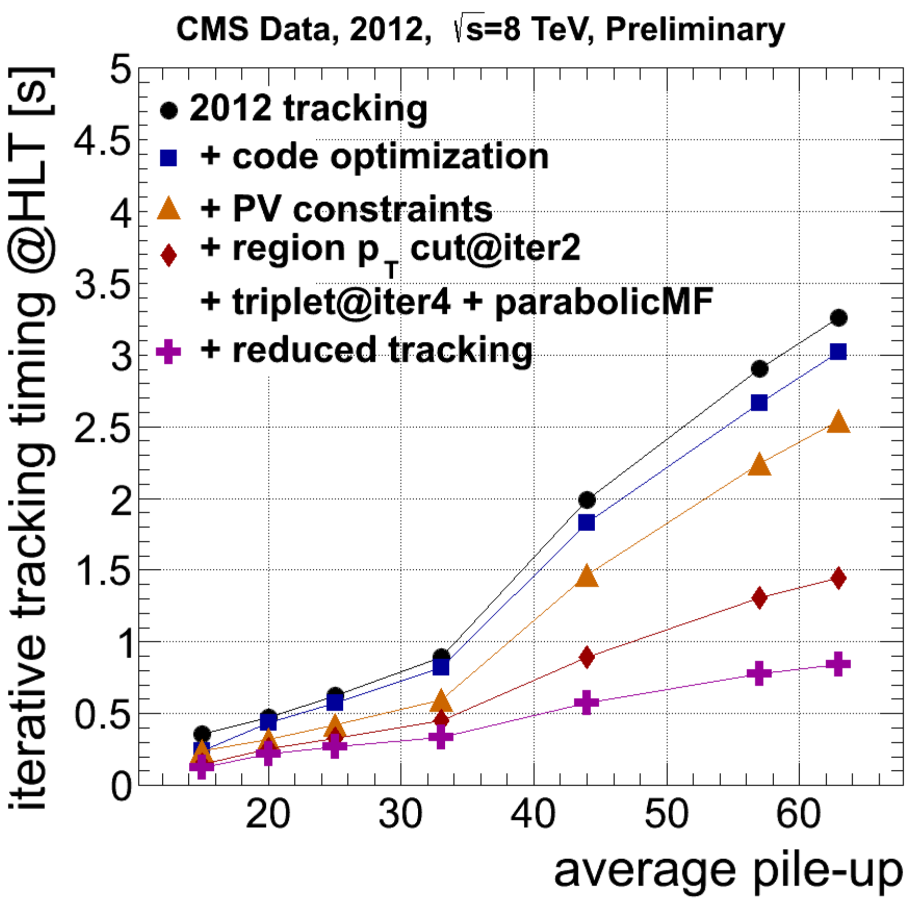
***Sandy Bridge-EP*** cores: reference

- 2012 HLT nodes

***Haswell*** cores: ~120% of **SB**

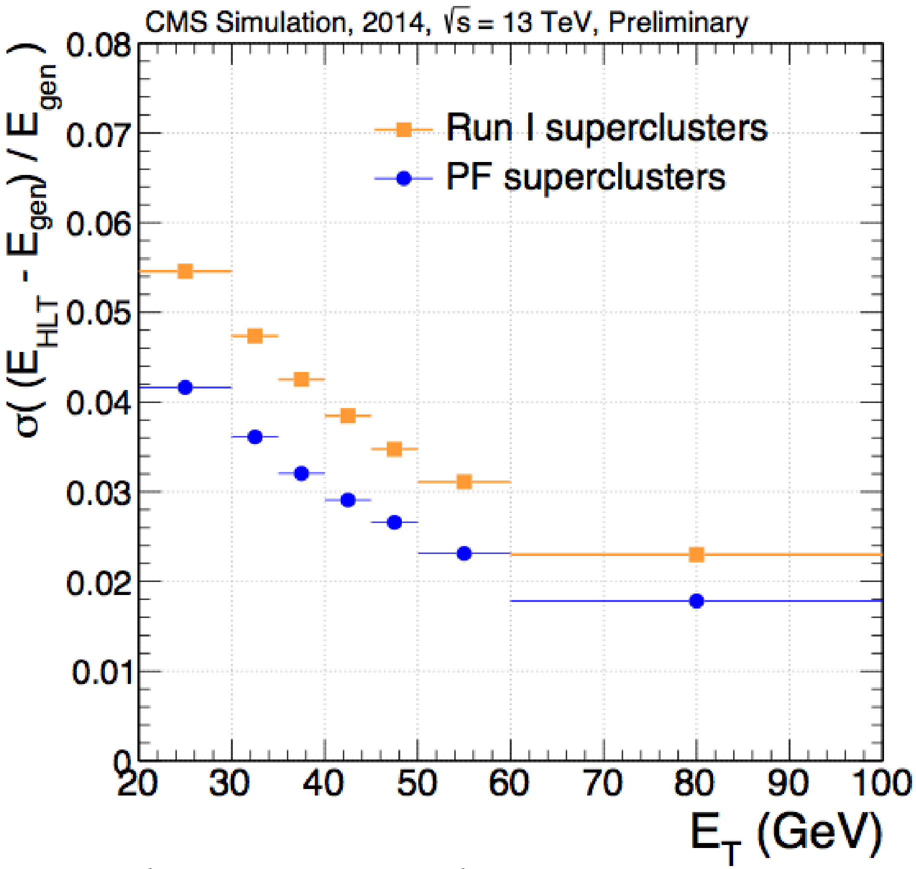
- expected 2015 HLT nodes
- preliminary value

# Tracking at HLT




- *iterative tracking* used at HLT since 2011 for particle flow reconstruction
- at the highest luminosity in 2012
  - running on **~3%** of the events
  - using **~30%** of the processing time
- in 2015, plan to extend the usage
  - to **5~10%** of the events!
- in the past 18 months
  - code optimisations (shared with offline reconstruction)
  - constrain to the primary vertex
  - re-tune parameters
  - remove less useful iterations
- **x2 to x3 times faster**

# Electrons at HLT




- new electron *superclusters* reconstruction, with improved energy calibrations
  - best-case scenario, using offline energy corrections
  - simplified, dedicated HLT energy corrections are under development

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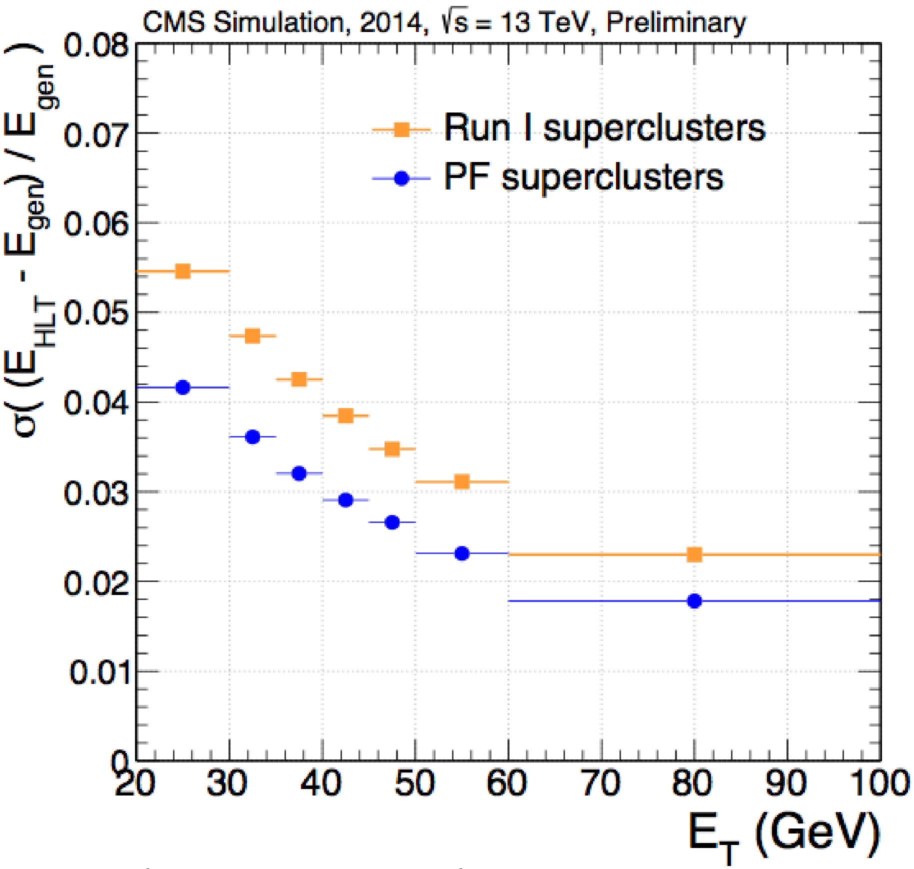
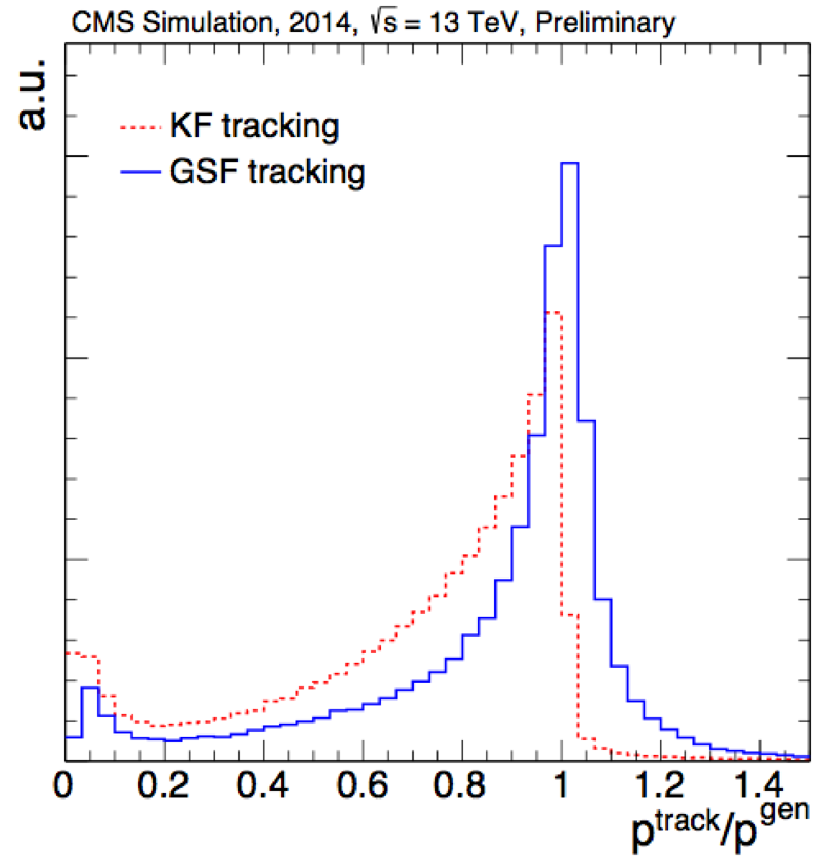
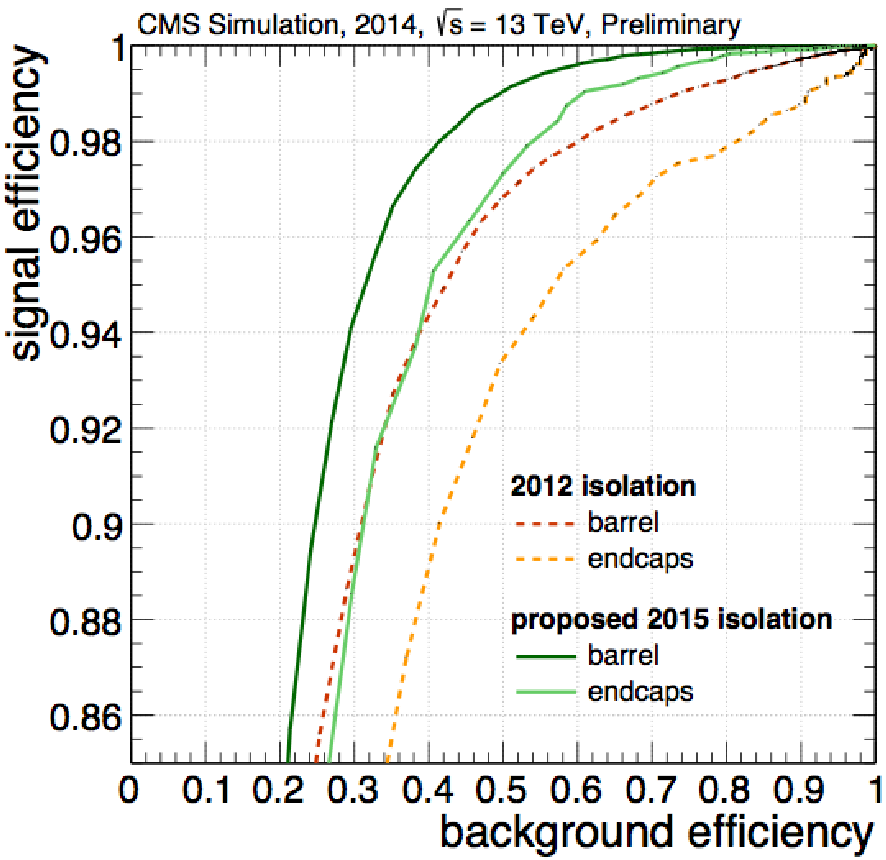



- new electron *superclusters* reconstruction, with improved energy calibrations
  - best-case scenario, using offline energy corrections
  - simplified, dedicated HLT energy corrections are under development
- general use of Gaussian Sum Filter tracking for electrons
  - algorithm optimised to achieve affordable processing time

# Electron Isolation at HLT




- improved **electron isolation** based on particle flow reconstruction

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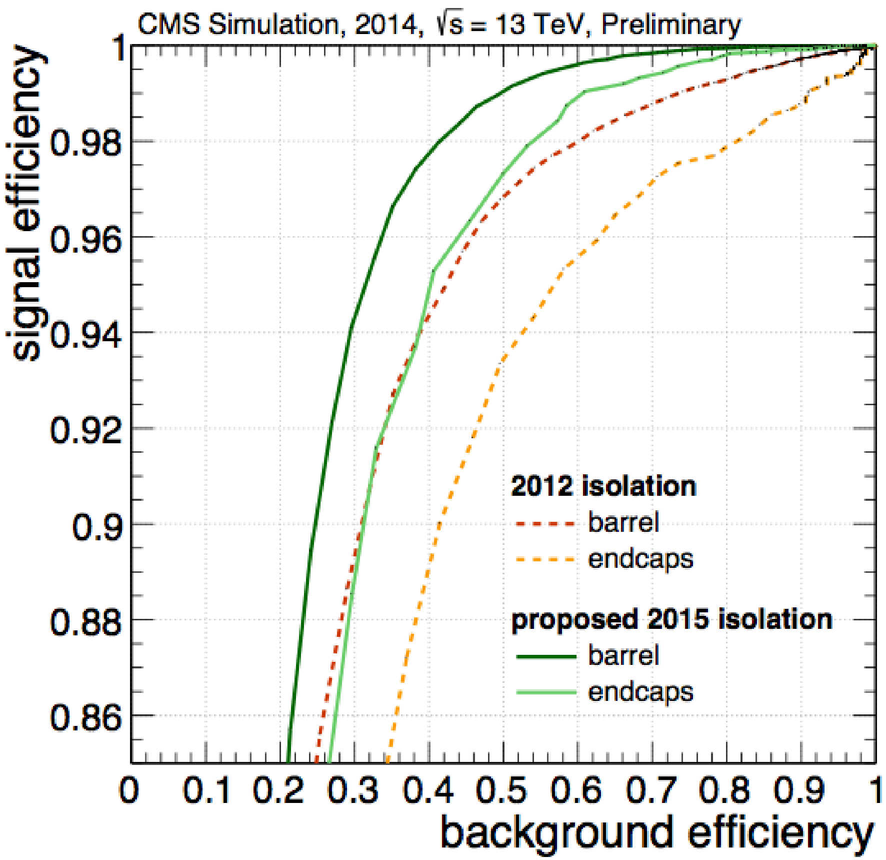
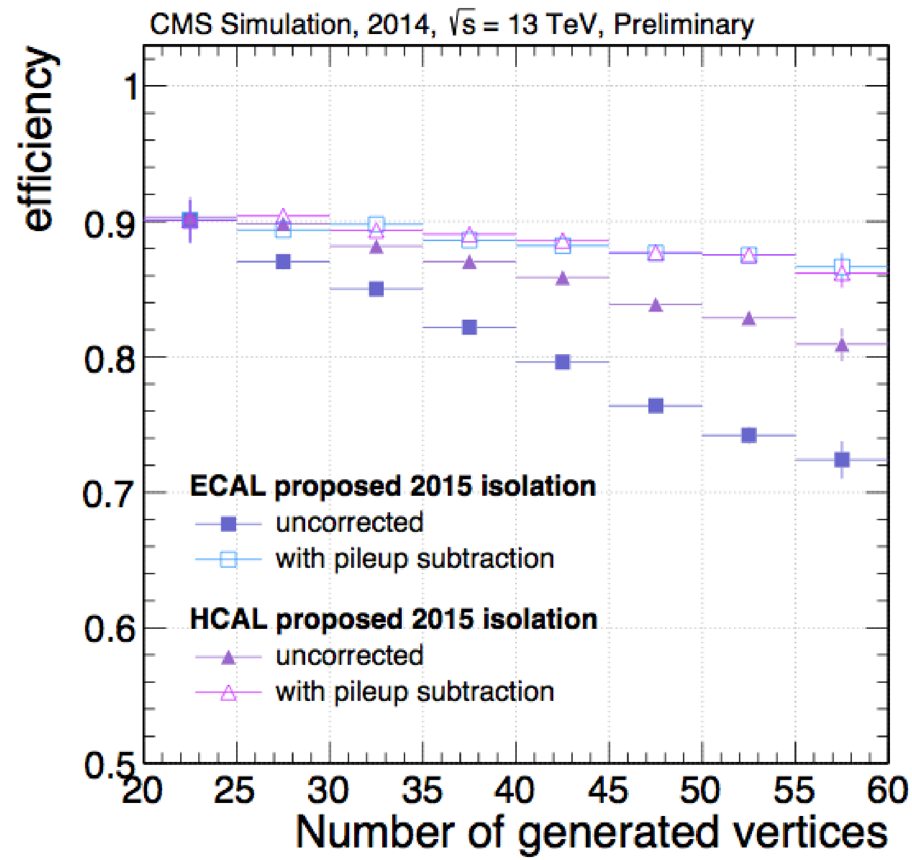
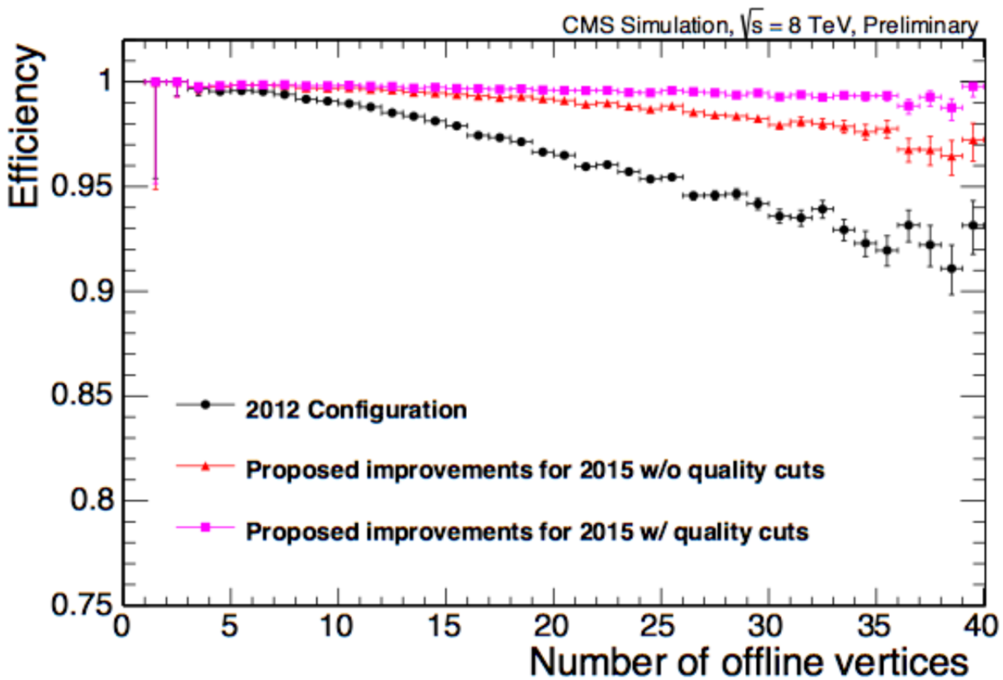



- improved **electron isolation** based on particle flow reconstruction
- improved efficiency at high pileup thanks to **pileup subtraction**
  - barrel region
  - all curves normalised to 90%

# Muons at HLT

- improved local and global **muon reconstruction**



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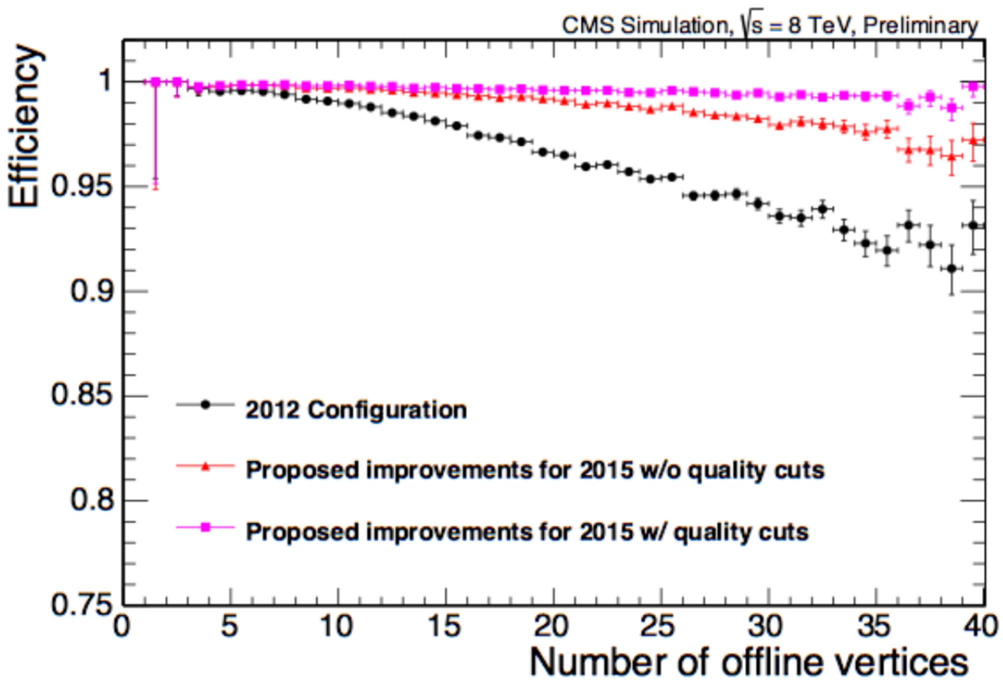
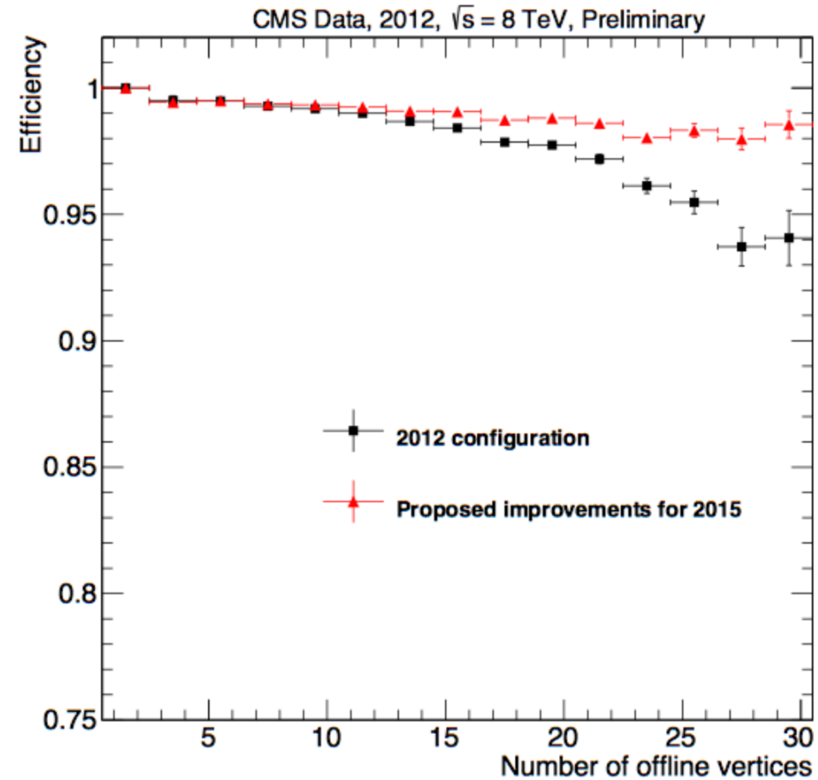



- improved isolation efficiency at high pileup
  - based on paticle flow reconstruction with **pileup subtraction**
  - barrel region

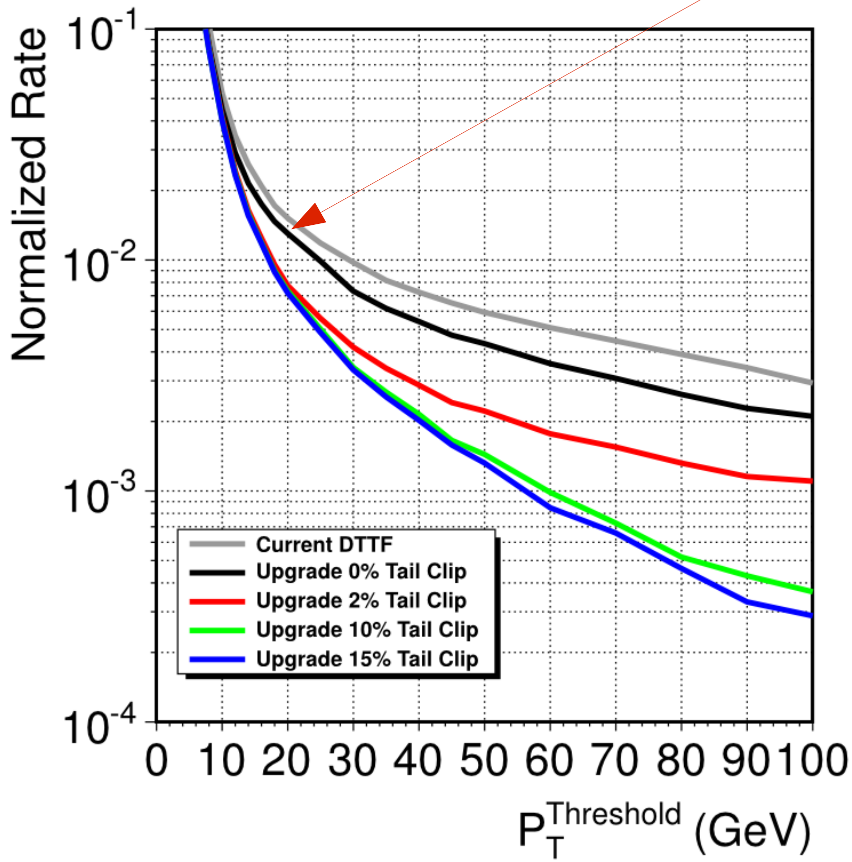
# His last bow

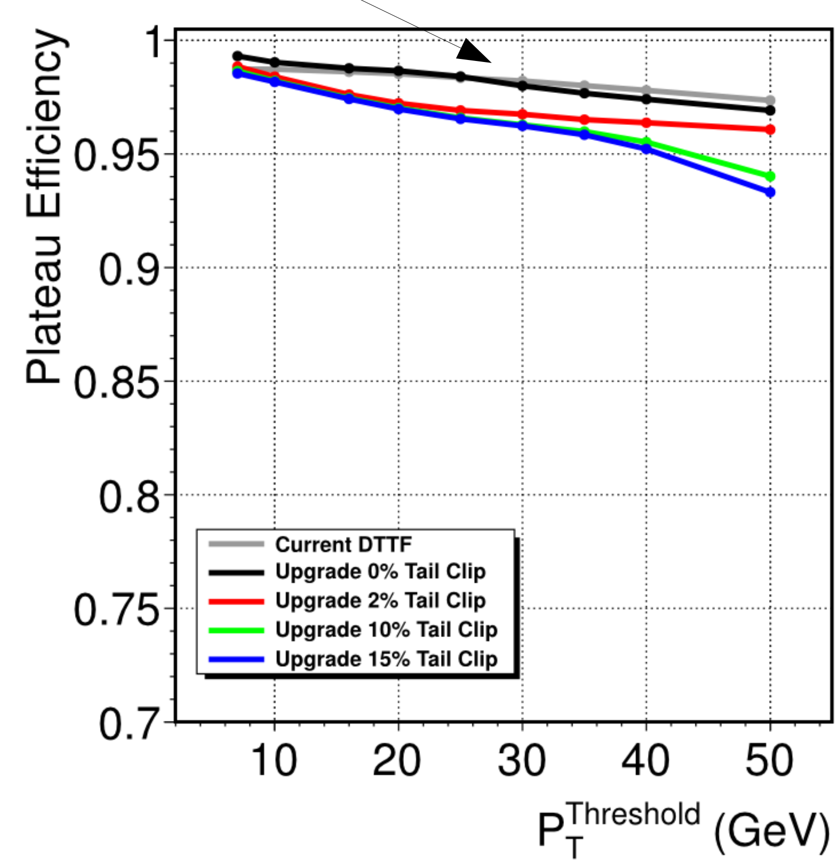
- the main strategy is to focus on the most difficult scenario
  - **13 TeV, $\mathcal{L}$ = 1.6e34 $cm^{-2}s^{-1}$**
  - **25 ns operations**
  - **~45 pileup events per interaction**
- new L1 hardware should be ready for the first beams
  - possibility to commission the new hardware during the 50 ns operations
- baseline L1 algorithms are available
  - further improvements are still being studied
- online reconstruction at HLT has been completely re-optimised since 2012
  - faster, more efficient
  - better rejection of pileup
- the actual triggers are being defined in these weeks


400GB
FIL021 L3
FIL040 L3
FIL055 L3
FIL018 L3

# L1 muon trigger upgrade (2016)

rate reduction by a **factor 2 ~ 3**, with a **similar** efficiency (barrel region)




- unique track finder for all muon detectors (DT, CSC, RPC)
- new muon pT assignment (bigger LUTs, post-processing)